LAKE WEBSTER/THE BACKWATERS DIAGNOSTIC STUDY
KOSCIUSKO COUNTY, INDIANA

INTRODUCTION

Lake Webster and the Backwaters area are situated east of North Webster, Indiana (Figure 1). Specifically, the lakes are located in Section 10, 11, 12, 13, 14, and 15, Township 33 North, Range 7 East, in Kosciusko County; Latitude: 41^{o}19’32”; Longitude: 85^{o} 40’47”. The lakes are two of several lakes that lie within the Upper Tippecanoe River Watershed. The lakes’ watershed encompasses approximately 31,275 acres (12,662 ha) or 49 square miles (127 km^2). Water from this area drains through the Tippecanoe River to the Wabash River, eventually reaching the Ohio River in southwestern Indiana.

The Lake Webster watershed formed during the most recent glacial retreat of the Pleistocene era. The advance and retreat of the Saginaw Lobe of a later Wisconsian age glacier as well as the deposits left by the lobe shaped much of the landscape found in northeast Indiana (Homoya et al., 1985). In Whitley, Noble, and Kosciusko counties, the receding glacier left a nearly level topography dotted with a network of lakes, wetlands, and drainages.

Changes to the area’s hydrology altered this natural landscape. Settlers to the area drained wetlands to farm the area’s rich soil. Today, approximately 70% of the Lake Webster watershed is utilized for agricultural purposes. Lake Webster itself is a product of altered hydrology. The lake was formed in the mid to late 1800’s when a dam was constructed on the Tippecanoe River, flooding several natural lake basins to form the 585 acre (237 ha) impoundment. Higher water levels transformed the Backwaters area from semi-permanently flooded marsh habitat to deeper aquatic habitat.

Several studies have documented changes in Lake Webster as well. Recent work by the Clean Lakes Program reports increased phosphorus concentrations in the lake compared to data collected in 1976 as part of the National Eutrophication Study. Volunteer lake monitoring data from the past decade shows a trend towards decreasing Secchi disk transparency. Lake residents have observed an increased density in rooted plants, particularly Eurasian water milfoil, in the lake. This evidence suggests that human induced pressures are artificially accelerating the natural eutrophication process in Lake Webster.

To gain a better understanding of the factors affecting the lake’s health, the Lake Webster Association applied for and received funding through the Indiana Department of Natural Resources Lake and River Enhancement Program for a lake and watershed diagnostic study. The purpose of the study is to describe the conditions and trends in Lake Webster and the Backwaters area as well as their watershed, identify potential problems, and make prioritized recommendations addressing these problems. The study included a review of historical studies, interviews with lake residents and state/local regulatory agencies, collection of lake and stream water quality samples, an inventory of aquatic macrophytes and plankton, and field investigations identifying land use patterns. This report documents the results of the study.

REVIEW OF EXISTING INFORMATION

Lake and Watershed Physical Characteristics

Lake Webster and the Backwaters are two of several lakes located along the Tippecanoe River east of North Webster, Indiana (Figure 2). The Tippecanoe River originates at Crooked Lake in Whitley County and flows northwest through Whitley and Noble Counties. Five lakes are located upstream of the Backwaters on the Tippecanoe River: Crooked Lake, Big Lake, Smalley Lake, Baugher Lake, and Wilmot Pond. Upstream of the Backwaters, the Tippecanoe River has several tributaries, many with additional lakes located along their reaches as well. Other smaller drainages, including Gaff Ditch, flow directly to Lake Webster and the Backwaters.

Table 1 summarizes the surface area, volume, and other geographic information for Lake Webster, the Backwaters Area and their watershed. Lake Webster and the Backwaters watershed encompasses approximately 31,275 acres (12,662 ha) or 49 square miles (127 km^2). This results in a watershed area to lake area ratio of approximately 40:1. Watershed size can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive more pollutants (sediments, nutrients, pesticides, etc.) from runoff than lakes with smaller watersheds. Consequently, for lakes with large watershed to lake ratios, watershed activities can potentially exert a greater influence on the health of the lake than lakes possessing small watershed to lake ratios. Conversely, for lakes with small watershed to lake ratios, shoreline activities may have a greater influence on the lake's health than is the case for lakes with large watershed to lake ratios.

Table 1. Physical Characteristics of Webster and the Backwaters Lakes/Watersheds

Characteristic	Lake Webster	The Backwaters
Surface Area	585 acres (237 ha)	189 acres (76.5 ha)
Maximum Depth	52 feet (15.8 m)	7 feet (2.1 m)
Mean Depth	12.5 feet (3.8 m)	< 6 feet (< 1.5 m)
Volume	5,550 acre-ft ($6.8x10^6$ m^3)	515 acre-ft ($6.4x10^5$ m^3)
Shoreline Length	42,5000 ft (12,957 m)	17,500 ft (5,335 m)
Shoreline Development	2.4	2.2
Subwatershed Size	2,502 acres (1,013 ha)	28,773 acres (11,649 ha)
Combined Watershed Size	31,275 acres (12,662 ha)	
Combined Watershed:Lakes Area Ratio	Approximately 40:1	

Bathymetric maps showing depth contours for each lake provide additional information on the lakes' physical structure. A bathymetric map for Lake Webster and the Backwaters is presented in Figure 3. Several authors (Blatchley, 1901; Shipman 1977; Pearson, 1985, 1989, 1995, and 1999) suggest that damming of the Tippecanoe River in the 1800's raised the water level enough to flood five small lakes, forming one large lake, Lake Webster. The bathymetric map lends evidence to this idea. Five

distinct basins are scattered throughout what is now Lake Webster. Depth-area and depth-volume curves (Figures 4-7) were prepared from the bathymetric map (IDNR, 1977). Figure 4 shows that Lake Webster has an extensive shallow area, much of which is less than 10 feet (3 m) deep. This area covers approximately 387 acres (157 ha) or about 68% of the total lake area. Figure 5 shows that volume increases uniformly with depth until about the 35-foot depth (10.5 m) where the steeper curve indicates a greater change in depth per unit of volume. In other words, the deepest waters of Lake Webster contain a relatively small volume.

Figure 6 shows that shallow depths less than 5 feet (1.5 m) deep characterize most of the Backwaters. This area covers approximately 192.4 (78 ha) acres or about 95% of the total lake area. Likewise, nearly all the volume of the Backwaters occurs in water less than 5 feet (1.5 m) deep (Figure 7).

The depth-area and depth-volume curves are extremely useful in illustrating important relationships between depth, volume, and area. For example, if a particular rooted aquatic plant can grow in water up to ten feet (3 m) deep, the potential habitat for this plant is approximately 405 acres (164 ha) in Lake Webster and all 189 acres (76.5 ha) of the Backwaters. Knowing this, cost estimates for aquatic plant control or other lake treatments can be easily calculated for a given area and water volume. A lake's physical morphometry affects the fish community structure as well. (More detailed explanations of how the lake's morphometry impacts the biota in the lake are provided in the following sections.)

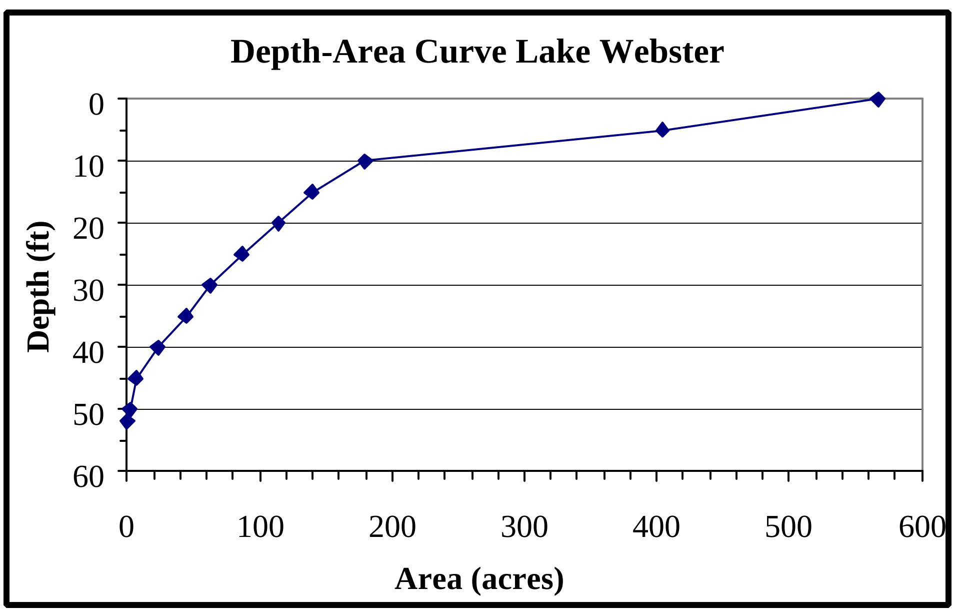


Figure 4. Depth-Area Curve for Lake Webster.

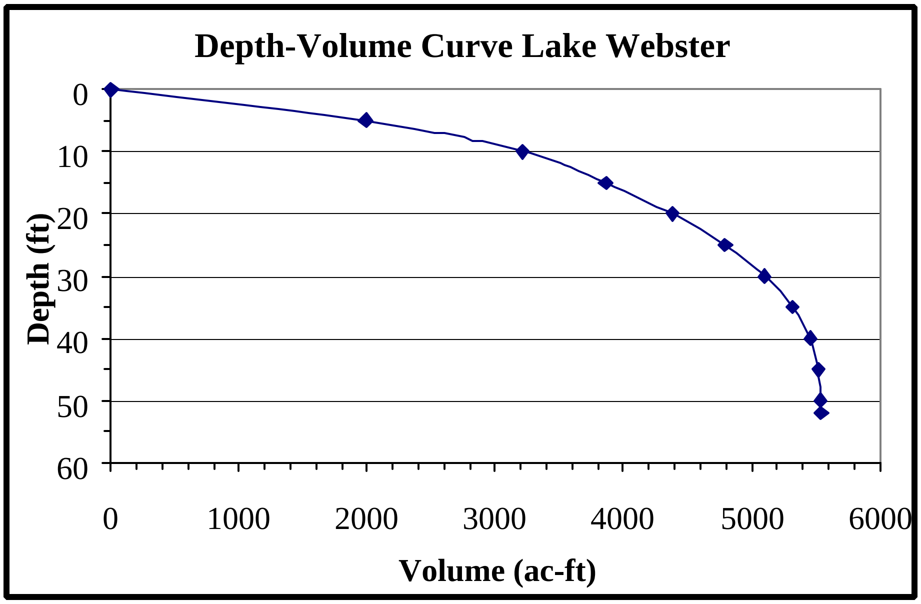


Figure 5. Depth-volume curve for Lake Webster.

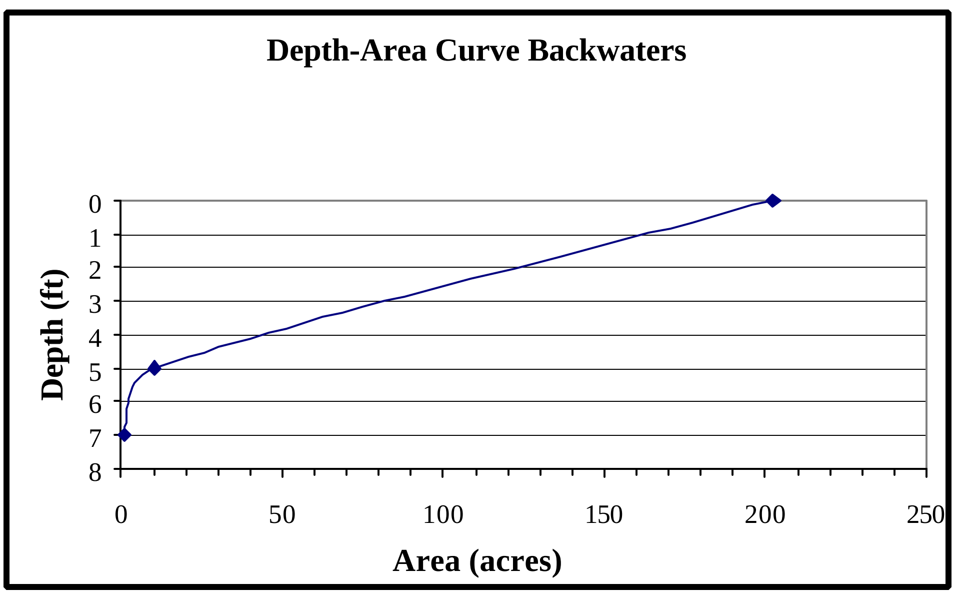


Figure 6. Depth-area curve for the Backwaters area.

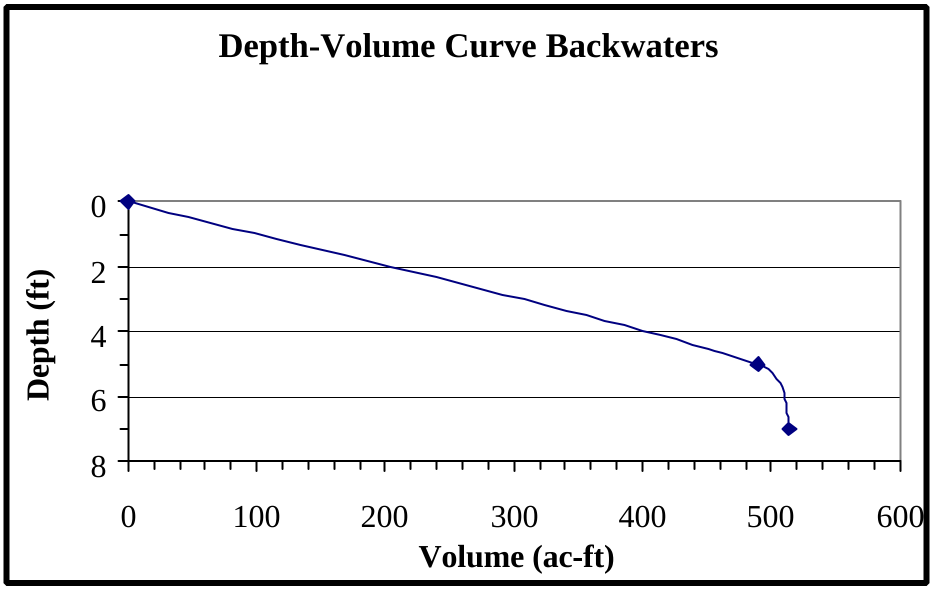


Figure 7. Depth-volume curve for Backwaters.

Climate

The climate in Kosciusko, Noble, and Whitley counties is characterized as cool and humid with winters that typically provide enough precipitation, in the form of snow, to supply the soil with sufficient moisture to minimize drought conditions when the hot summers begin. The average daily winter temperature is around 26 degrees Fahrenheit (-3 ^{o}C); the summer average is close to 70 degrees (21 ^{o}C). The highest temperature ever recorded was 103 degrees (39 ^{o}C) on July 17, 1976. Total annual precipitation averages 35 to 38 inches (89 to 97 cm). In 1999 just over 35 inches (89 cm) of precipitation was recorded at Columbia City, Indiana in Whitley County. Although the difference between the annual total precipitation in 1999 compared to the average does not seem to be drastic, the year was characterized by very extensive dry periods in March, July, and October through December. Some months saw better than average precipitation while those stated above saw levels far below the normal monthly average.

Soils

The soil types found in Kosciusko, Noble, and Whitley Counties are a product of the original parent materials deposited by the glaciers that covered this area 12,000 to 15,000 years ago. The main parent materials found in these three counties are glacial outwash and till, lacustrine material, alluvium, and organic materials that were left as the glaciers receded. The interaction of these parent materials with the physical, chemical, and biological variables found in the area (climate, plant and animal life, time, and the physical and mineralogical composition of the parent material) formed the soils located in Kosciusko, Noble, and Whitley Counties today.

Soils in the watershed, and in particular their ability to erode or sustain certain land use practices, can impact the water quality of a lake. For example, highly erodible soils are, as their name suggests, easily erodible. Soils that erode from the landscape are transported to waterways or waterbodies where they impair water quality and often interfere with recreational uses by forming sediment deltas in the waterbodies. In addition, such soils carry attached nutrients which further impair water quality by fertilizing macrophytes (rooted plants) and algae. Soils that are used as septic tank absorption fields deserve special consideration as well. The presence of highly erodible soils and the use of septic fields in the Webster/Backwaters watershed are described in further detail below.

Highly erodible soils

The scope of the diagnostic study did not allow for exact calculation of acreage of highly erodible soils in the Lake Webster watershed. General estimates were obtained for the three counties in which the watershed lies. Koscuisko County reports that approximately 30% of the county is mapped in highly erodible soil units (Sam St. Clair, personal communication). In Whitley County approximately 60% of the county is mapped as highly erodible. Most of the highly erodible soils occur in the northern portion of the Whitley County (Amy Lybarger, personal communication). Wayne Stanger of the Natural Resources Conservation Service (NRCS) (personal communication) estimates a similar amount of acreage for Noble County. Work done by the Purdue University Cooperative Extension Service on the Upper Tippecanoe River Hydrologic Unit Area confirms that much of the highly erodible land in the Upper Tippecanoe River watershed is concentrated in the Lake Webster watershed as well as the upper Grassy Creek watershed.

Septic use

As is common in rural areas, septic tank and septic tank absorption fields are utilized for wastewater treatment in the much of the Webster/Backwaters watershed. Approximately one third of the homes around the lakes rely on septic systems to treat their household waste. The remaining two thirds of the homes surrounding the lakes are sewered to the North Webster municipal wastewater treatment plant. The use of septic systems to treat wastewater impacts both surface and groundwater throughout the watershed. However, septic system use on property immediately adjacent to the lakes has the greatest potential to impact the lakes and, therefore, is the focus of this summary.

Septic treatment systems use a septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the septic tank effluent to levels that protect the groundwater from contamination. Groundwater is one of the water sources to the lakes. Consequently, the type of soil located adjacent Lake Webster and the Backwaters and the soil's ability to function as a septic tank absorption field will affect the lakes' water quality.

A variety of factors can affect a soil's ability to function as a septic absorption field. Whether or not a soil is typically ponded during a portion of the year has obvious impacts on its ability to serve as a septic field. Frequently ponded soils offer little or no treatment to waste effluent. Untreated effluent is often simply flushed to the lake. Soils located on sloped land may have difficulty treating wastewater as well. Septic fields sited on these soils may require enlarged fields to treat the waste effluent. Soils that have been disturbed through excavation and fill or compaction are also unsuitable for wastewater discharge using soil absorption fields.

In addition, soils with very slow percolation rates are limited in their ability to serve as septic fields. These soils can become clogged due to the high levels of organic material in the septic effluent. Like soils on sloped land, these soil types require very large absorption fields due to the low permeability of the soil. Septic tank absorption fields in these soils with slow percolation rates have a higher rate of failure than fields with higher percolation rates, due to the potential for clogging. Septic field failure, with ponding of wastewater at the surface, may allow the untreated wastewater to flow overland to the lake.

The NRCS ranks each soil series in terms of its limitations for use as a septic tank absorption field. Each soils series is placed in one of four categories: slightly limited, moderately limited, severely limited, or unsuitable. Use of septic absorption fields on soils in the moderately or severely limited soils generally requires special design, planning, or maintenance to overcome the limitations. Table 2 summarizes the soil series located adjacent to the unsewered areas of Lake Webster and the Backwaters Area in terms of their suitability for use as a septic tank absorption field. Figure 8 shows the location of the soil types in the unsewered area of the lakes.

Table 2. Soil Types Adjacent to Lake Webster and the Backwaters Area

Symbol	Name	High Water Table (ft)	Suitability for Septic Tank Absorption Field
Ao	Aquents-Urban land complex, rarely flooded	-	unsuitable, flooding
He	Histosols and Aquolls	-	unsuitable, ponding
Ht	Houghton muck, undrained	+1-1.0	severe, subsides, ponding, percs slowly
Re	Rensselaer loam	+0.5-1.0	severe, ponding
ClB, ClC	Coloma loamy sand	>6.0	severe, poor filter
OrA, OrB, OrC	Ormas loamy sand	>6.0	severe, poor filter
MrD3	Miami clay loam	>6.0	severe, percs slowly
CrA	Crosier loam	1.0 – 3.0	severe, percs slowly, wetness
RlA, RlB, RlC	Riddles fine sandy loam	>6.0	moderate, percs slowly
WlB	Wawasee fine sandy loam	>6.0	moderate, percs slowly

Source: Soil Survey of Kosciusko County

Aquents-Urban land complex, rarely flooded, (Ao) occurs mainly on the edges of lakes, where marshes have been filled with soil material. The unit is rarely flooded for brief periods by stream or lake overflow. Typically, Aquents are a mixture of surface soil, subsoil, and underlying material 2-15 feet (0.6–4.5 m) deep over the original soils. Histosols and Aquolls (He) are poorly drained soils in depressions and potholes and along the border of lakes and streams. These soils are frequently ponded by runoff from the higher adjacent soils or by lake or stream overflow. The water table is near or above the surface most of the year. Because of the flooding and ponding with both the Aquents and Histosols, these soils are generally unsuitable for septic tank absorption fields.

Houghton muck, undrained, (Ht) is a nearly level, very poorly drained soil in broad depressions on outwash plains and around lakes. It is frequently ponded by runoff and/or by lake overflow. The availability water capacity is very high and runoff is very slow or ponded. The water table is near or above the surface most of the year. Because of ponding, this soil is unsuitable for septic tank absorption fields.

Like Houghton muck, Rensselaer loam (Re) is a very poorly drained soil. It is found in slight depressions on broad outwash plains and terraces, along small drainageways, and in depressions on till plains, terraces, and outwash plains. Because of ponding, this soil is unsuitable for septic tank absorption fields.

Coloma loamy sand (ClB, ClC) is a somewhat excessively drained soil with rapid permeability. Ormas loamy sand (OrA, OrB, OrC) is a well-drained soil. The surface horizons are rapidly permeable while the subsoil exhibits a moderately rapid permeability with the underlying material possessing a very rapid permeability. Due to the rapid permeability, these soil types do not provide adequate filtering capability for septic tank absorption fields and may cause pollution of the ground water.

Miami clay loam (MrD3) is a well-drained soil with moderately slow permeability. Due to the slow percolation, this soil is severely limited for use as septic tank absorption fields. Like Miami clay loam, Riddles fine sandy loam (RlA, RlB, RlC) and Wawasee fine sandy loam (WlB) are well-drained soils. They are found on till plains and on benches and the tops of ridges on moraines. They have moderate permeability, which moderately limits their use as a site for septic tank absorption fields.

Crosier loam (CrA, CrB) is a somewhat poorly drained soil on till plain swells and in swales and drainageways on moraines. Permeability is moderately slow, and the water table is at a depth of 1 to 3 feet (0.3 to 0.9 m) during the winter and spring. Because of the wetness and slow permeability, this soil is severely limited in its use as a site for septic tank absorption fields.

Pollution from septic tank effluent can contribute to eutrophication, or nutrient enrichment, of the lake. The nutrients present in septic tank effluent can fertilize algae and macrophytes in the lake, promoting algae blooms and macrophyte growth. In addition, septic tank effluent potentially poses a health concern for lake users. Swimmers, anglers, or boaters that have body contact with contaminated water may be exposed to waterborne pathogens. Fecal contaminants can be harmful to humans and cause serious diseases, such as infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illness.

Soil Summary

The type of soils in a watershed and the land uses practiced on those soils can affect a lake's health. The Webster/Backwaters watershed contains a higher concentration of highly erodible soils compared to watersheds located lower in the Upper Tippecanoe watershed. Soils eroding from these highly erodible land contribute sediment to the lakes reducing the lake's water quality and interfering with recreational uses of the lakes. Nutrients attached to eroded soils will help fertilize algae and rooted plants. Consequently, conservation methods and best management practices (BMPs) should be utilized when soils are disturbed in these areas. This includes development of shoreline property as well as farming in highly erodible soils.

Soil type should also be considered in siting septic systems. Some soils do not provide adequate treatment for septic tank effluent. Much of the Webster/Backwaters shoreline that currently utilizes septic systems to treat household waste is mapped in soils that rate as severely limited or generally unsuitable for use as a septic tank absorption field. This is typical of much of Indiana. Research by Dr. Donald Jones suggests that 80% of the soils in Indiana are unsuitable for use as a septic tank absorption field (Grant, 1999). Careful consideration should be given to sewering the remaining homes around the lakes. While it may be expensive, a sewer system would eliminate a portion of the nutrient load reaching the lakes, improving their water quality and limiting their productivity.

Land Use

Figure 9 and Table 3 present land use information for Lake Webster's watershed. Land use data was obtained from the Indiana Gap Analysis project. (Land use categories shown in Table 3 are general in nature; Appendix 1 breaks the data into more detailed categories as well as providing land use by subwatershed.) Nearly 70% of the land in the watershed is used for agricultural purposes, including cropland, pasture, and agricultural woodlots. Land use in the Lake Webster watershed is typical of the counties in which it lies. In Kosciusko County, 72% of the land in the county is used for agricultural purposes. Agricultural land accounts for 69% of the total land in Noble County and 77% of the total land in Whitley County (U.S. Census of Agriculture, 1999). Forested land and wetlands account for much of the remaining land in the Webster watershed (17.8% and 6.8% respectively). Less than one percent of the land in the watershed is utilized for residential or commercial purposes.

Table 3. Land Use in the Lake Webster Watershed

Land use	Area (acres)	Area (hectares)	Percent of watershed
Agricultural	21375	8654	69.8%
Forested	5472	2215	17.8%
Wetland	2097	849	6.8%
Residential/commercial	187	76	0.6%
Other	206	83	0.7%
Open water	1328	538	4.3%
Total	**30665**	**12415**	**100%**

Source: Indiana Gap Analysis Project

In 1998, approximately 49% of the cropland in Kosciucko County was planted in corn and 39% in soybeans (U.S. Census of Agriculture, 1999). Conservation tillage practices are utilized throughout the county. In 1998, no-till was practiced on approximately 17% of the farmland planted in corn and mulch tillage (a tillage method that leaves at least 30% of residue cover on the surface after planting) was practiced on approximately 13% of the farmland planted in corn. For fields planted in soybeans, the percentage of farmland utilizing conservation tillage methods was higher: 57% in no-till, 25% in mulch-till (Julie Harrold, Kosciusko County SWCD, personal communication).

Whitley and Noble Counties report similar percentages in cropland use and slightly higher conservation tillage use. In 1998, 39% of the cropland in Whitley County was planted in corn while 44% was planted in soybeans. Landowners practiced no-till farming on approximately 34% of the land planted in corn and approximately 68% of the land planted in soybeans (Amy Lybarger, District Conservationist, personal communication). Lybarger noted that use of no-till practices on cropland planted in corn has declined in recent years. However, she also observed a decrease in the use of wide-row bean planting.

Approximately, 46% of the cropland was planted in corn and 44% in soybeans in Noble County during the same year (U.S. Census of Agriculture, 1999). Of the land planted in corn, landowners utilized no-till practices on 35%. No-till use was greater on land planted in soybeans; landowners utilized no-till practices on 55% of that land (Sherm Liechty, District Conservationist, personal communication).

Wetlands

Wetlands provide a variety of functions for an ecosystem. These functions include filtering sediment and nutrients in runoff, storing water, allowing for groundwater recharge and discharge, and providing nesting habitat for waterfowl and spawning sites for fish. By performing these roles, healthy, functioning wetlands often improve the water quality and biological health of streams and lakes located downstream of the wetlands.

The land use table above (Table 3) indicates that wetlands account for approximately 6.8% of the Webster/Backwaters watershed. Table 4 presents the acreage of wetlands by type. The IDNR (Indiana Wetland Conservation Plan, 1996) estimates that approximately 85% of the state's wetlands have been filled. The greatest loss has occurred in the northern counties of the state such as Koscuisko, Whitley, and Noble counties. The last glacial retreat in these counties left level landscapes dotted with wetland and lake complexes. Development of the land in these counties for agricultural purposes altered much of the natural hydrology eliminating many of the wetlands. The 1978 census of agriculture found that drainage is artificially enhanced on 38%, 35%, and 45% of the land in Koscuisko, Noble, and Whitley Counties, respectively (cited in Hudak, 1995).

Table 4. Acreage and Classification of Wetland Habitat in the Webster/Backwaters Watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of watershed
Forested	1,227.5	497.0	4.0%
Shrubland	505.3	204.6	1.6%
Herbaceous	364.3	147.5	1.2%
Total	**2,097.1**	**849.1**	**6.8%**

Source: Indiana Gap Analysis Project

As part of the United States Army Corps of Engineers study on the Upper Tippecanoe River Basin (1995), the Kosciusko County Natural Resources Conservation Service identified 28 potential wetland restoration sites. Eight of these sites are located within the Webster/Backwaters watershed (Figure 10). These sites total approximately 200 acres (81 ha). While this figure is small relative to the size of the Webster/Backwaters watershed, the habitat would increase water storage and filter nutrients and sediments from runoff which in turn would decrease downstream flooding and improve downstream water quality. Based on the figures for artificially enhanced drainage above, it is likely that additional wetland restoration sites exist in the Webster/Backwaters watershed. Restoration of these areas could further add to the benefits for the watershed.

Natural Communities and Endangered, Threatened and Rare Species

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species, high quality natural communities, and natural areas in Indiana. The database was developed to assist in documenting the presence of special species and significant natural areas and to serve as a tool for setting management priorities in areas where special species or habitats exist. The database relies on observations from individuals rather than systematic field surveys by the Indiana Department of Natural Resources. Because of this, it does not document every occurrence of special species or habitat. At the same time, the listing of a species or natural area does not guarantee the presence of the listed species or that the

listed natural area is in pristine condition. The database includes the date that the species or special habitat was last observed in a specific location.

According to the database, two species are listed as endangered by the federal government. In Kosciusko County a mussel, the northern riffleshell (*Epioblasma torulosa rangiana*), and the Indiana bat (*Myotis sodalis*) are on the federal list of endangered species. Weathered shells of the northern riffleshell were last found just outside of the watershed boundary in 1991. The Indiana Bat has not been documented in the watershed since 1955. It was last observed in the Tri-County Fish and Wildlife Area. The three counties harbor many state listed plants, molluscs, insects, fish, amphibians, reptiles, birds, and mammals species as well as several high-quality natural communities. Appendix 2 presents a complete listing of these species and natural communities observed in all three counties.

There are several state nature preserves and unique areas that are home to many rare species and communities near Lake Webster. Crooked Lake Nature Preserve in the southeast portion of the watershed contains listings in the database for blandings turtle (*Emydoidea blandingii*), two different kinds of high quality forest: upland dry-mesic, and upland mesic, high quality lake community, four different species of pondweed (*Potamogeton* spp.), and three other plant species: horse-tail spikerush (*Eleocharis equisetoides*), shining ladies'-tresses (*Spiranthes lucida*), and lesser bladderwort (*Urticularia minor*). The database notes the presence of cisco (*Coregonus artedi*) in Crooked Lake; these cisco were last observed in 1997. Near the western portion of the watershed, the Pisgah marsh area contains listings for 14 different species of flora and fauna, most of which are listed as endangered in the state. Appendix 3 provides a complete listing of all of the high quality natural areas and rare species within and near the Lake Webster watershed. The appendix also contains a map showing the last known location or sighting for a number of the more familiar species. Care should be exercised in the watershed to preserve these rare natural communities and the species that inhabit them.

Fisheries

A few reports, including Miles (1915), Ricker (1942), and Bechtol (1955), provide some detail on certain aspects of the lake's fishery prior to the 1970's. In 1976, however, the IDNR began systematic fisheries surveys on Lake Webster and the Backwaters area. Fish surveys in 1985, 1988, 1990, 1995, 1998 followed the initial 1976 survey. In addition, the IDNR has conducted several muskie surveys from 1982 to 1999 to track the muskie stocking effort. Creel surveys were recorded in 1987 and 1990.

1976

The 1976 fisheries survey involved three hours of electrofishing and 288 hours of gill netting. This sampling effort resulted in the collection of 1,638 fish from 21 species. Bluegill dominated the catch accounting for 40.7 % of the individuals collected followed by gizzard shad (16.7%), yellow perch (12.2%), redear (7.1%), and brown bullhead (5.4%). Gizzard shad, largemouth bass, and carp dominated the catch by weight.

Many of the fish collected exhibited slow to average growth rates and low to average weights. The bluegills exhibited low weights and below average growth rates with 32.6% of the bluegills collected being of catchable size (6.0 inches or greater). Gizzard shad, yellow perch, and redear also had slow growth rates. Most of the yellow perch were small in length. In contrast, 85% of the redears were of catchable size (6.0 inches or greater). The largemouth bass population exhibited average weights and above average growth rates.

The results of the survey were not surprising in light of the conditions at Lake Webster. Being a shallow lake with a large, predominantly agricultural watershed, Webster is ideal for macrophyte growth. In lakes with many macrophytes, smaller forage fish have ample shelter from predators resulting in larger forage fish populations. However, a large forage fish population increases competition among individuals leading to slower growth rates and stunted populations. IDNR biologists recommended some limited macrophyte control and the introduction of northern pike, a predator, to help control the forage fish population.

<u>1985</u>

The IDNR conducted a second comprehensive fisheries survey in 1985. Sampling effort included 2.25 hours of electrofishing, 288 hours of gill netting, and 264 hours of trap netting. A total of 1,474 fish representing 22 species were collected. As in the 1976 survey, just over half of the indivduals collected were bluegills (51.1%). Gizzard shad (12.3%), black crappie (8.9%), largemouth bass (7.8%), and yellow bullhead (6.7%) accounted for most of the remaining 48.9%. Carp and gizzard shad dominated the catch by weight accounting for 20.6% and 16.1%, respectively. Older bluegill continued to exhibit below average weights. The growth rates and weights of younger bluegills, however, were above average. The growth rates and weights of largemouth bass were average.

The IDNR biologists noted little difference between the fish community in 1976 and that seen in the 1985 survey. Many of the differences could be accounted for by the differences in sampling methods. However, redear and yellow perch populations showed a decline that could not be accounted for by sampling methods. Bozek et al. (1999) determined that perch (*Perca flavescens*) and white sucker (*Catostomous commersoni*) were the most common prey items in muskie diets of northern Wisconsin Lakes. This could offer one possible explanation for the reduction of perch numbers in the survey, but the muskie introduction did not appear to reduce the bluegill population as intended. Past laboratory and field studies have shown that muskie do not prefer sunfish as prey items (e.g. Mauck and Coble 1971; Weithman and Anderson 1977; Deutsch 1986; Wahl and Stein 1988) when prey such as suckers (*Catostomidae*), minnows (*Cyprinidae*), and perch (*Percidae*) are available. Smaller fish and non-game fish continued to utilize much of the lake's production at the expense of larger, sport fish.

<u>1988</u>

In 1988, IDNR biologists conducted a third fisheries survey. Sampling effort included 1 hour of electrofishing, 192 hours of gill netting, and 192 hours of trap netting. The effort yielded a total of 1,261 fish representing 18 species. Bluegill dominated the catch (62.7%) followed by largemouth bass (9.8%), gizzard shad (5.2%), and black crappie (3.9%). Largemouth bass (27.4%), gizzard shad (20.5%), bluegill (15.5%), and carp (9.2%) dominated the catch by weight. In total, game fish comprised 93% of the individuals collected and 68% of the weight.

Consistent with earlier studies, bluegills exhibited below average weights and older bluegills displayed below average growth rates. Largemouth bass weights were average, but the younger bass were slower growing. Black crappie and yellow perch exhibited average weights.

The large catch of small bluegills and the relatively stable bass population suggested that the muskie introduction had not affected the lake's bass or bluegill populations. In constrast however, yellow perch and redear populations are somewhat reduced possibly as a result of the muskie introduction. IDNR biologists again recommend limited macrophyte control and restrictions on developing the remaining undeveloped portions of the shoreline as a means of improving the Webster fishery.

1990

The 1990 fisheries survey resulted in a catch of 1,310 fish representing 19 species. Bluegills continued to dominate the catch accounting for 47% of the individuals and 17% of the weight. Gizzard shad, black crappie and largemouth bass comprised 24%, 10%, and 3.6% of the individuals respectively. Gizzard shad dominated the catch by weight (21%). Sport fish accounted for 74 % of the individuals caught and 54% of the weight. As in past surveys, the bluegills, particularly the older ones, exhibited slow growth rates, and there was no evidence to suggest that the muskies were affecting the bluegill or bass populations.

The IDNR also conducted a "mark and recapture" study on the largemouth bass population in 1990. The technique involves marking fish with fin tags or clips during an initial sampling trip. Based on the number of marked fish that are recaptured in subsequent sampling trip(s) a fairly simple mathematical model can be used to calculate a population estimate for that species. The Schnabel estimate for the bass population in Webster was 8,037. IDNR biologists suggested this estimate was low due to the difficulty in sampling in the Backwater area. Number of bass per acre of lake surface in Webster (13/ac.) was comparable to other northern Indiana lakes (17/ac.).

1995

The IDNR conducted its fifth fish community survey for Lake Webster in 1995. Sampling during the survey consisted of 0.75 hours of electrofishing, 192 hours of gill netting, and 144 hours of trap netting. The effort yielded a catch of 1,385 fish representing 19 species. Bluegills dominated the catch by number and weight accounting for 63.7% of the individuals and 20.9% of the weight. Largemouth bass, gizzard shad, and black crappie followed in relative abundance and weight. Many small bluegill were collected again in the 1995 survey, and the few older fish collected had exceptionally slow growth rates. Bass showed average weights and growth rates compared to other northeastern Indiana lakes.

1998

The 1998 fish community survey was conducted between July 13 and 15, 1998. The sampling effort for the survey consisted of one hour of electrofishing, 144 hours of trap netting, and 144 hours of gill netting. A total of 1,783 fish representing 19 species were collected during the survey. Bluegills once again dominated the catch by number (64%) and weight (32%). Gizzard shad ranked second in relative abundance (10%) followed by yellow perch (6%), black crappie (6%), and largemouth bass (5%). Sport fish represented 89% of the fish collected during the 1998 survey.

Creel Surveys

Creel surveys were conducted in 1987 and 1990. Results from the two surveys were similar. 75% of the anglers on Webster were boat anglers, while 25% fished from the shore. Anglers were split almost evenly between weekend and weekday fishing. Most anglers (78%) fished for either bluegills or largemouth bass. Most anglers (72%) caught bluegills. The study also asked anglers' opinoin on the muskie stocking effort. Two thirds of the anglers interviewed were in favor of the muskie stocking. The remaining third was divided between opposition to the stocking and indifference to the stocking.

Muskie Stocking

In 1978, Lake Webster was stocked with roughly 48,500 muskellunge (muskie) fry. Like northern pike, muskie are predators and as such may provide enough biological pressure needed to alter composition of the fish community. The survival of stocked fish can be related to the size at which they were stocked, the presence of a predator already in the ecosystem (Wahl et al., 1995), and the availability of suitable habitat and forage. In selecting Lake Webster for muskie stocking, IDNR biologists considered several of these factors including available forage, plant cover, and the existing fish community (Pearson, 2000). Despite this careful planning, two years after the initial stocking of muskie fry the IDNR did not find any muskie in their gill net surveys. The reasons for the stocking effort failure are unclear, but likely involve a variety of factors.

In 1981, a second effort to establish a self-sustaining muskie population in Webster began with the release of 350 muskie fingerlings (10-12 inches in length). Since then, between approximately 300 and 3,800 fingerlings have been released each year except 1987 and 1996. Muskie fingerlings were not stocked in 1987 or 1996.

In 1988 IDNR began stocking only muskie fingerlings from the Fawn River State Fish Hatchery. Fisheries biologists hoped that stocking larger muskie would result in improved survival and ultimately a naturally reproducing population. Margenau (1999) suggests that survival of young muskie after stocking can be attributed to three main factors; stress associated with stocking, prey availability, and predation. Survival of muskie has improved since IDNR began using larger forage fed fingerlings, but successful natural reproduction has not been documented. Many of the previously mentioned biotic and abiotic variables, in addition to the size of fish stocked, affect the ability to establish a naturally reproducing and sustainable muskie population. Predicting the exact outcome of an experimental program is often difficult for fisheries managers. IDNR has conducted and continues to conduct surveys tracking the success of the muskie introduction and its effect on the Webster fish community.

A detailed investigation of the muskie fishery in Lake Webster was conducted in 1998 to determine the density of adult muskies, angler interest, and catch success, to measure the impact of muskies on other fishes, and to assess muskie habitat preferences and reproductive success. IDNR began sampling for muskie in the spring with the use of trap nets. Captured muskie were marked with a left pectoral fin clip and released. Later in the spring biologists sampled again, but used gill nets this time. They were looking for muskie with left pectoral fin clips (recaptures) and those without fin clips (captures). Two different mathematical models that use the number of marked (M), captured (C), and recaptured (R) fish to estimate populations resulted in population estimates of 1,218 for the Petersen estimate (N=C*M/R+1) and 1,144 using the Schnabel estimate ($N=sum(C_t *M_t)/sumR+1$). Schanbel estimates were calculated for each day (t) of the sampling. These numbers, combined with the area of the lake, resulted in a density estimate of approximately 1.5 muskie per acre of lake.

A creel survey was conducted at Lake Webster and the Backwaters from April 12, 1998 to November 28, 1998 to estimate angler effort and catch. Anglers fished a total of 43,929 hours on Webster through the duration of the creel survey with the peak of fishing pressure in May (26% of the total hours). The creel survey interviews included 1,380 angler party interviews of which 23% were fishing for muskie, an increase of nearly 17% since 1990. In 1990, fishermen harvested only 4 muskie compared to 1998 when anglers harvested 27. Another positive sign for the Webster fishery was the six-fold increase in the number of muskie caught and released in 1998 compared to 1990. Angler interest was expanding with the improved muskie fishery.

Based on the results of this study, IDNR fisheries biologists concluded that Lake Webster provides a high-quality muskie fishery. The lake's fishery attracts many anglers. Nearly 90% of the muskie anglers rate the muskie fishing as good. IDNR biologists also believe that the stocking of muskie has had no adverse effects on the native fish community. A review of the fish community surveys from 1976 to 1998 confirms this belief. Minor fluctuations appear from year to year for some species but none of the data illustrates a drastic reduction as a result of muskie predation with the possible exception being a reduction in perch numbers between 1976 and 1995. (It should be noted, however, that the pounds of perch collected in the 1998 survey were the most since the surveys began.) The IDNR recommended continued stocking of Lake Webster with 3,870, forage-fed, muskie fingerlings (10 in.) annually.

<u>Summary</u>

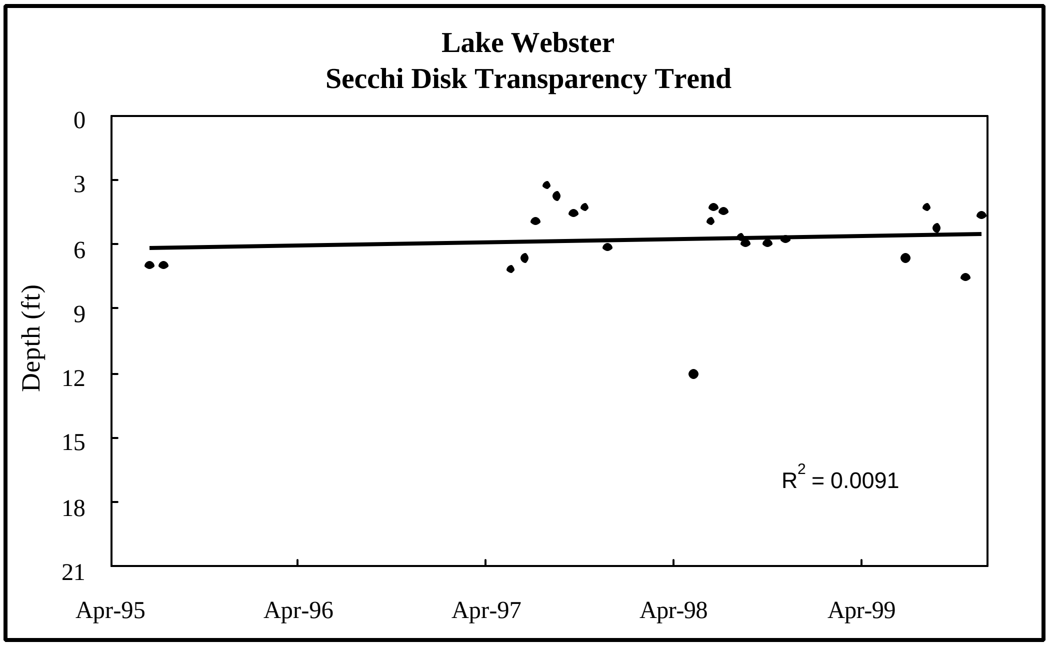
Table 5 below summarizes the fish community composition from 1976 to 1998. Appendix 4 provides a complete listing of fish species found in three historical surveys. In general, the fish community in Webster has remained fairly stable in the past two and a half decades. Bluegills dominate the fishery accounting for 40.7% to 67.2% of the number of individuals collected each survey year. Those bluegills collected have been small in size, but most have average lengths of 5-6 inches (13-15 cm). Age 4 bluegills should be of catchable length (6.0 + inches), but as a result of slow growth rates, bluegill of this size are rare in Webster. The bass population has fluctuated with inconsistent reproductive success, which is common in other northeastern Indiana bass populations.

The most notable changes in the fish community composition from 1976 to 1995 were the decline in yellow perch and redear from the 1976 survey to the 1985 survey and the decline in carp from 1985 to 1988. 183 yellow perch were collected in 1976 compared to catches ranging from 10 to 43 in subsequent surveys. The perch rebounded to account for almost 5% of the weight of all fish collected in the 1998 survey. The number of redear sampled in 1998 was double the number collected in the 1995 survey, but was still considerably lower than the number of fish from the first survey in 1976. A total of 36 carp were collected in the first two surveys, however, only 8 carp were collected in the following three surveys.

The dominance of small bluegills in Webster is likely to continue in the future. The physical characteristics of the lake and its watershed create conditions ideal for plant growth. Because much of the lake is 6 feet deep or less, light is readily available to macrophytes. In addition, these plants are nourished by a constant influx of phosphorus from the watershed. INDR surveys state that phosphorus from non-point sources accounts for approximately 88% of phosphorus input to the lake. The heavy plant cover provides shelter to smaller forage fish like bluegill, protecting them from predatory fish like bass and muskie. Bluegills use the dense cover to hide or escape from predators which leads to excellent survival rates for small individuals. This, in turn, increases the competition for resources in the lake creating stunted fish.

Water quality also plays a role in determining the fish community structure. As will be detailed in the following sections, Lake Webster has low water clarity. The volunteer Secchi disk transparency data collected over the past years shows a slight decrease in water clarity (Figure 11). This data is further supported by the Secchi disk transparency measurement of 4 feet (1.2 m) recorded during this study. 1.2 m is below the median Secchi disk transparency measurement of 6 feet (1.8 m) for Indiana lakes suggesting Webster has worse water clarity than most other Indiana lakes. Poor water clarity favors prey species as it can inhibit predators' ability to locate prey. Thus, the poor water clarity may be assisting the large population of bluegills.

Figure 11. Secchi Disk Transparency Trend for Lake Webster.



The amount of oxygen present in the lake may affect the size of predator populations. Data from the 1990's show that approximately 27% to 50% of Webster's water column contained oxygen during those sampling periods (Tables 7, 8, 9, and 13). Because oxygen diffuses to water from the air, the portion of the water that contains oxygen is likely the upper portion of the lake (epilimnion). Photosynthesizing organisms (macrophytes and algae) also contribute to the epilimnion oxygen content. Predators, however, prefer deep holes as resting spots. These holes may not contain sufficient oxygen to support great numbers of predators. The physical size of these holes may also play a role in limiting predator numbers.

The dominance and stability of the bluegill and bass populations suggests that the muskie introduction has had no effect on these fish. IDNR biologists had hoped the introduction would reduce the bluegill population and consequently free up more resources for the remaining bluegills to utilize. The constancy of the bass population indicates that the addition of more predators has not harmed the largemouth bass. Muskie survival may not be sufficient to limit resources for the bass.

Muskie survival has increased throughout the stocking program's history. Several other steps may be taken to ensure continued success. The IDNR should consider a spring stocking program of yearling fish rather than a fall stocking of fingerlings. The fall fingerlings stocking programs can be a very effective in lakes with low predator densities which is not the case at Lake

Webster. Largemouth bass, the resident predator in Webster, commonly prey upon muskellunge up to 9 inches and sometimes larger. In addition, mature muskellunge will prey upon their own species. A large individual is capable of preying upon another that may be more than one-half its own size. Stocking yearling muskie, which are typically 13 to 14 inches (33-36 cm) in size compared to the fingerlings which are 7 to 11 inches (18-28 cm) in size, may improve survival.

Consideration of the feasibility of stocking spring yearling muskellunge is recommended for maintaining the muskellunge fishery at Lake Webster.

Placement of hatchery fish in a lake also plays a role in survival of stocked fish. An effective strategy to increase survival rates may be to release the stocked fish near vegetative cover (e.g. dense macrophytes, stumps) in shallow water for protection from predators until they become acclimated to their new surroundings. Muskellunge research in other states has shown that stocked fingerling muskellunge lack a “predator avoidance” instinct for the first few days after being released. This results from the stress of transport and introduction to an unfamiliar environment and subsequently leads to high initial mortality rates. After a couple of weeks, the stocked muskellunge resume normal avoidance behavior. The IDNR has and intends to continue stocking muskie near aquatic vegetation for these reasons. A continuation of this practice is recommended as an additional measure to decrease initial stocking mortality rates at Lake Webster.

Table 5: Relative Abundance of Selected Fish Species in Lake Webster from 1976 to 1998.

Fish species	**1976**	**1985**	**1988**	**1990**	**1995**	**1998**
Bluegill	40.7%	51.2%	67.2%	46.6%	63.7%	64.4%
Largemouth bass	4.4%	7.8%	9.8%	3.6%	10.3%	4.8%
Gizzard shad	16.7%	12.3%	5.2%	23.7%	8.6%	9.8%
Black crappie	4.2%	8.9%	3.9%	9.9%	4.5%	5.7%
Yellow perch	11.2%	1.4%	2.9%	3.3%	< 1%	6.1%
Redear	7.1%	2.2%	1.4%	2.4%	1.9%	3.0%
Carp	1.1%	1.2%	< 1%	< 1%	< 1%	<1%

Unionids

The Tippecanoe River, and in particular its upper reaches, is historically known for its diverse community of unionids including several federally endangered species. The IDNR is currently working on a natural lakes mussel survey documenting the presence of mussels in each natural lake. In 1998, Lake Webster was surveyed for the presence of mussels. Three unionid species including the fatmucket clam (*Lampsilis siliquoidea*), pondmussel (*Ligumia subrostrata*), and the giant floater clam (*Pyganodon grandis*) were found. Two exotics, the Asiatic clam (*Corbicula fluminea*) and zebra mussels (*Dreissena polymorpha*), were also found in the lake. Zebra mussels were observed throughout Lake Webster and the Backwaters during the macrophyte survey conducted as part of this diagnostic study.

Historical Water Quality

A search of published information on Lake Webster and the Backwaters identified several reports including several Indiana Department of Natural Resources (IDNR) fisheries surveys dating back to 1976, a 1976 lake assessment conducted by the U.S. Environmental Protection Agency as part of their National Eutrophication Survey, additional lake assessments conducted by the Indiana Department of Environmental Management's (IDEM) Clean Lakes Program, and records from volunteer lake monitors. (The volunteer monitoring program is also part of the Indiana Clean Lakes Program.) A citizen volunteer monitor still collects Secchi disk transparency on Lake Webster.

A summary of selected historic water quality parameters (including this study) for Lake Webster is given in Table 6. Secchi disk transparency decreased from 5.9 feet (1.8 m) in 1973 (USEPA, 1976) to 4.3 feet (1.3 m) in 1998 (CLP, 1999). These trends are indicative of increasing eutrophication. Secchi disk transparency collected by a citizen volunteer was variable as expected, but there was a general trend for decreasing transparency over time (Figure 11). The mean total phosphorus concentration in Lake Webster has risen from 0.019 mg/L in 1973 (USEPA, 1976) to 0.1496 mg/L in 1998 (CLP, 1999) (Figure 12). This trend has a fairly steep slope and approximates a straight line. Concentrations of total phosphorus (TP) have varied somewhat over time (Table 6). TP concentrations in the surface waters (epilimnion or 'epi') were relatively low but the TP concentrations in the bottom waters (hypolimnion or 'hypo') were quite high. A consistent pattern existed of lower concentrations in the surface waters and higher concentrations in the bottom waters. That suggests that phosphorus was being released from the sediments during stratified conditions.

Table 6. Summary of Historic Data for Lake Webster.

DATE	SECCHI DISK (ft)	pH	TP (mg/L)	TP (mg/L)	DATA SOURCE
5/2/73	5.6		0.028	0.025	USEPA, 1976
8/4/73			0.021	0.014	USEPA, 1976
10/15/73	5.9		0.019	0.025	USEPA, 1976
7/1/91	3.6	7.7	0.054	0.237	CLP, 1991
8/15/94	4.3	7.95	0	0.277	CLP, 1994
6/18/95	7				Volunteer monitor
7/15/95	7				Volunteer monitor
5/21/97	7.2				Volunteer monitor
6/18/97	6.7				Volunteer monitor
7/10/97	5				Volunteer monitor
7/31/97	3.3				Volunteer monitor
8/20/97	3.8				Volunteer monitor
9/22/97	4.6				Volunteer monitor
10/12/97	4.3				Volunteer monitor
11/27/97	6.2				Volunteer monitor
5/13/98					Volunteer monitor
6/15/98	5				Volunteer monitor
6/22/98	4.3				Volunteer monitor
6/29/98	4.3	7.9	0.022	0.277	CLP, 1998
7/10/98	4.5				Volunteer monitor
8/14/98	5.7				Volunteer monitor
8/24/98	6				Volunteer monitor
10/5/98	6				Volunteer monitor
11/9/98	5.8				Volunteer monitor
6/30/99	6.7				Volunteer monitor
8/11/99	4.3				Volunteer monitor
8/12/99	3.9	7.5	0.045	0.269	Present study
8/31/99	5.3				Volunteer monitor
10/25/99	7.6				Volunteer monitor
11/25/99	4.7				Volunteer monitor

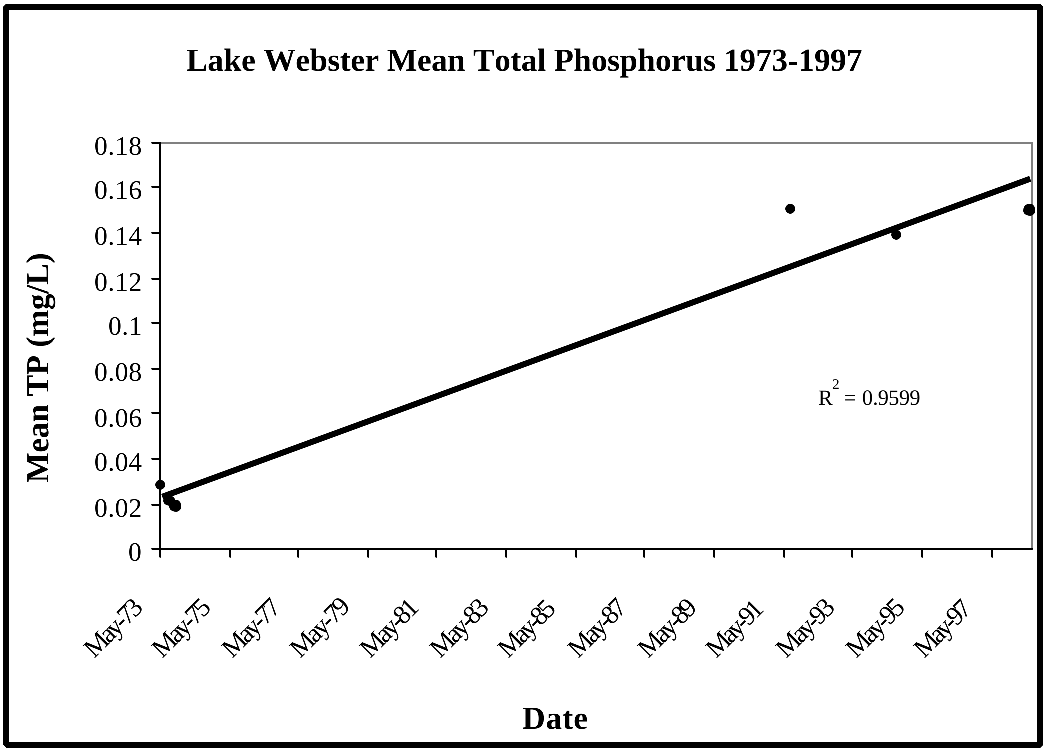


Figure 12. Mean Total Phosphorus of Lake Webster.

Three previous comprehensive lake assessments were conducted in 1991, 1994 and 1998 under the auspices of the Indiana Clean Lakes Program. Lake Webster results for these three assessments are given in Tables 7 - 9. Similar results for the Backwaters are available for 1994 and 1998 (Tables 10 and 11). As part of these assessments, a trophic state index (TSI) score was determined using the Indiana Trophic State Index (see more on TSIs under the Discussion section of this report).

Table 7. Water Quality Characteristics of Lake Webster, 7/1/91.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.3	7.1	-
Alkalinity	183.75mg/L	224.7mg/L	-
Conductivity	400 µmhos	418 µmhos	-
Secchi Disk Transp.	3.61 feet	-	6
Light Transmission @ 3 ft	1%	-	4
1% Light Level	10.46 feet	-	-
Total Phosphorus	0.054 mg/L	0.237 mg/L	3
Soluble Reactive Phos.	0.008 mg/L	0.218 mg/L	3
Nitrate-Nitrogen	0.221 mg/L	0.262 mg/L	0
Oxygen Saturation @ 5 ft.	126.12%	-	2
% Water Column Oxic	26.85%	-	4
Plankton Density	25062 per L	-	3
Blue-Green Dominance	Yes	-	10
		TSI Score	41

Table 8. Water Quality Characteristics of Lake Webster, 8/15/94.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.4	7.5	-
Alkalinity	159 mg/L	224 mg/L	-
Conductivity	380 µmhos	400 µmhos	-
Secchi Disk Transp.	4.3 feet	-	6
Light Transmission @ 3 ft	38%	-	3
1% Light Level	13 feet	-	-
Total Phosphorus	0.023 mg/L	0.277 mg/L	3
Soluble Reactive Phos.	0.003 mg/L	0.253 mg/L	3
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	3.51 mg/L	4
Organic Nitrogen	0.510 mg/L	<0.230mg/L	0
Oxygen Saturation @ 5 ft.	99.00%	-	2
% Water Column Oxic	50.00%	-	2
Plankton Density	33825 per L	-	4
Blue-Green Dominance	No	-	0
		TSI score	25

Table 9. Water Quality Characteristics of Lake Webster, 6/29/98.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8.3	7.5	-
Alkalinity	160 mg/L	198 mg/L	-
Conductivity	420µmhos	360 µmhos	-
Secchi Disk Transp.	4.3 feet	-	6
Light Transmission @ 3 ft	32.06%	-	3
1% Light Level	10.7 feet	-	-
Total Phosphorus	0.022 mg/L	0.277 mg/L	3
Soluble Reactive Phos.	0.006 mg/L	0.255 mg/L	3
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	1.654 mg/L	3
Organic Nitrogen	0.681 mg/L	0.706 mg/L	2
Oxygen Saturation @ 5 ft.	104%	-	0
% Water Column Oxic	28.57%	-	3
Plankton Density	24613 per L	-	3
Blue-Green Dominance	Yes	-	10
		TSI score	36

Table 10. Water Quality Characteristics of Backwaters, 8/15/94.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	8	8	-
Alkalinity	216.1 mg/L	216.1 mg/L	-
Conductivity	450 µmhos	450 µmhos	-
Secchi Disk Transp.	3.3 feet	-	6
Light Transmission @ 3 ft	25.00%	-	4
1% Light Level	1.5 feet		-
Total Phosphorus	0 mg/L	0.068 mg/L	1
Soluble Reactive Phos.	0 mg/L	0.005 mg/L	0
Nitrate-Nitrogen	0.05 mg/L	0.05 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	<0.018 mg/L	0
Organic Nitrogen	0.437 mg/L	0.437 mg/L	0
Oxygen Saturation @ 5 ft.	127%	-	2
% Water Column Oxic	100.00%	-	0
Plankton Density	12955 per L	-	2
Blue-Green Dominance	No	-	0
Chlorophyll *a*	32.07 µg/L	-	-
		TSI score	15

Table 11. Water Quality Characteristics of Backwaters, 6/29/98.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.52	-	-
Alkalinity	200.9 mg/L	-	-
Conductivity	510 µmhos	-	-
Secchi Disk Transp.	5.2 feet	-	0
Light Transmission @ 3 ft	37.68%	-	3
1% Light Level	12.3 feet	-	-
Total Phosphorus	0.095 mg/L	-	3
Soluble Reactive Phos.	0.072 mg/L	-	3
Nitrate-Nitrogen	0.059 mg/L	-	2
Ammonia-Nitrogen	0.098 mg/L	-	0
Organic Nitrogen	0.908 mg/L	-	3
Oxygen Saturation @ 5 ft.	1%	-	0
% Water Column Oxic	50%	-	2
Plankton Density	6532 per L	-	2
Blue-Green Dominance	No	-	0
Chlorophyll *a*	14.58 µg/L	-	-
		TSI score	18

Several dissolved oxygen profiles (D.O.) exist for Lake Webster (Figure 13). Each of these profiles shows a well-stratified lake with an extensive volume of anoxic (no oxygen) water. The depth of this anoxic zone appears to be increasing over time.

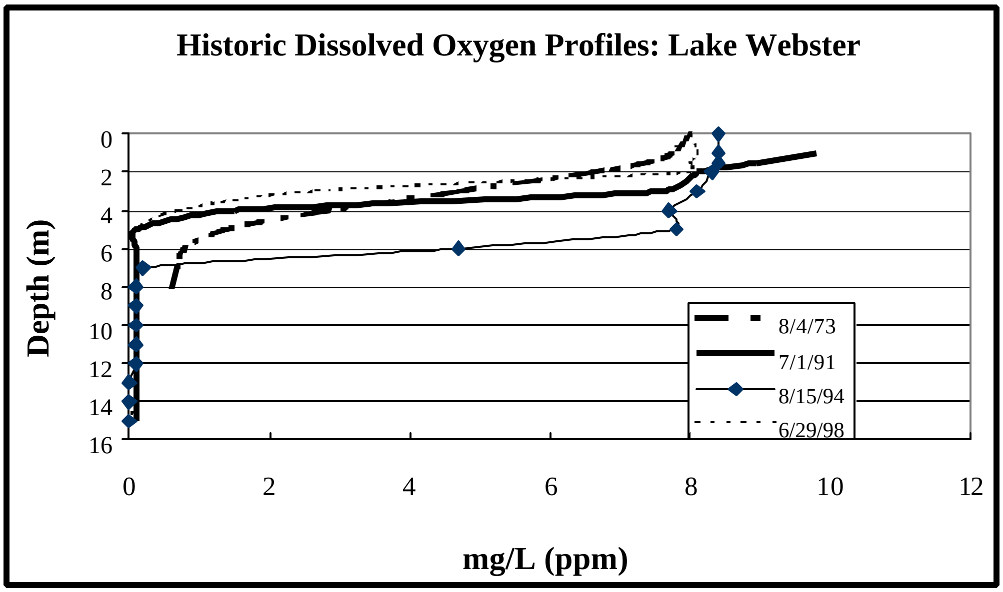


Figure 13. Compilation of five historic dissolved oxygen profiles measured from Lake Webster.

STUDY METHODS, RESULTS, AND DISCUSSION

Watershed Investigation

Methods

The Webster/Backwaters watershed was investigated on several occasions to identify areas of concern. The investigations included field inspection, interviews with lake residents, county NRCS biologists, and town officials, and aerial inspection via a small engine aircraft.

Results and Discussion

Storm Water

The town of North Webster has eleven regulated drains conveying storm water to Lake Webster. As legal drains, the town is responsible for their maintenance. These conduits drain storm water runoff from the east side of North Webster. Drains on the west side of State Road 13 carry storm water to Kuhn Ditch and eventually to Lake James, downstream of Lake Webster. According to Marshall Minnick, town of North Webster superintendent (personal communication), all of the legal drains are equipped with catch basins. A site inspection revealed the presence of numerous unregulated drains and concrete surface drains in addition to the regulated drains. Most of the drains, regulated and unregulated, transport runoff from the urban area around the lake, but some are extensions of drainages through agricultural areas. Lake residents at some of the drain outlets have observed the drains discharging heavy silt loads, dead animals, oil residue, and trash, including soiled diapers, during storm events. The locations of the legal drains, several of the larger unregulated drains, and surface gutters are shown in Figure 14.

In addition to the gross pollutants described above, these drains carry salts from road deicing, fertilizers leaching from lawns, and thermal pollution from pavement heating. All of the gross pollutants and unseen pollutants contribute to poor water quality in the lake. Organic pollutants increase biological oxygen demand (BOD) which in turn increases anoxia in the lake. Anoxia limits the volume of water available to fish and other aquatic organisms and increases the potential for release of phosphorus from bottom sediments.

To limit damage from storm water, it is advisable to install the most up-to-date treatment methods within the storm catchment areas. Several filters are available which can be installed directly into the storm drain line. These filters, if serviced regularly, will remove most of the sediment particulates and the nutrients or toxins attached to the particulates.

Agricultural Land Use

Approximately 70% of the watershed is utilized for agricultural purposes. This land use, particularly when done on highly erodible soils can have an impact on water quality downstream. Runoff from farms field can contain a variety of pollutants including nutrients (nitrogen and phosphorus), pesticides, sediment, and bacteria (*E. coli*). Several programs and best management practices (BMPs) have been developed to address non-point source pollution associated with agriculture. These programs and BMPs and their impact on water quality are discussed below.

Conservation Reserve Program

The Conservation Reserve Program (CRP), run by the U.S. Department of Agriculture, is a voluntary, competitive program designed to encourage farmers to establish vegetation on their property in an effort to decrease erosion, improve water quality, or enhance wildlife habitat. Ideal areas for this program include highly erodible lands, riparian zones, and farmed wetlands. In exchange for the plantings, farmers receive cost share assistance for the plantings and annual payments for their land. (See the Appendix 5: Additional Funding for more details on the Conservation Reserve Program.)

Removing land from production and planting it with vegetation has a positive impact on the water quality of lakes in the watershed. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones (1996) showed that ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores for their lakes. (A TSI is an indicator of lake productivity or health. Lower TSI scores indicate lower productivity or generally better water quality. See In-Lake Sampling Section for more details.)

Conservation Tillage

Removal of land from agricultural production may not be economically feasible in some cases. Conservation tillage offers the potential for reducing erosion without removing the land from production. Conservation tillage requires leaving some portion of the crop on the land after its harvest rather than completely tilling the soil under as is done in conventional tillage. No till is a type of conservation tillage. Depending upon the type of conservation tillage used reported decreases in sediment loading to waterways have ranged from 60 to 98 percent; reduction in phosphorus input range from 40 to 95 percent. Reductions of pesticide loadings have also been reported (Olem and Flock, 1990). In the review of Indiana lakes referred to above (Jones, 1996), lower TSI scores were observed in ecoregions with higher percentages of conservation tillage.

Buffer Strips

Buffer or filter strips and grassed waterways along drainages and riparian zones are effective BMPs. Filter strips slow runoff flows from adjacent agricultural areas and reduce flow volume by increasing infiltration of the runoff. Slower runoff velocities and reduced flow volumes will lead to decreased erosion downstream. Buffers also help stabilize stream banks. Vegetative strips filter sediments, nutrients, and pesticides from the runoff preventing them from reaching the lakes and streams. Buffer strips can reduce up to 80% of the sediment, 50% of the phosphorus, and 60% of the pathogens in runoff (Conservation Technology Information Center, 2000).

Buffer strips are effective in reducing sediments and nutrient runoff from feedlot or pasture areas as well. Olem and Flock (1990) report that buffer strips remove nearly 80% of the sediment, 84% of the nitrogen, and approximately 67% of the phosphorus from runoff from feedlots. In addition, they found a 67% reduction in runoff volume.

While the use of buffer strips was noted in some areas of the watershed, more can be installed. During a watershed tour, cows were observed in the Tippecanoe River upstream of the Webster/Backwaters area. The bank area from which the cows gained access to the river was devoid of herbaceous vegetation. Animal waste (nutrients and pathogens) and sediment are easily transported to the river under these conditions. Removing access to the river and planting a vegetative buffer strip along that portion of the bank will reduce sediment and nutrient loads in the river.

Recent work done in the Upper Tippecanoe River Hydrologic Unit, which includes the entire Lake Webster watershed, encouraged more landowners to implement conservation tillage and other BMPs on their land. The Purdue Cooperative Extension Service reported an increase in conservation tillage to the 1996 levels of 40% for corn and 80% for soybeans (Purdue Agronomy Extension, 2000). The project also boasts an increase in buffer strips and grassed waterways. Local NRCS offices note that these numbers have decreased since the project ended in 1996, but are still fairly high. Continued utilization of conservation tillage and other BMPs in the Lake Webster watershed would likely improve the water quality in the lake. Specific areas targeted for BMPs include Gaff Ditch from County Road 750 East (Whitley County) east to its headwaters and the Tippecanoe River from Big Lake west to Smalley Lake.

Shoreline Development
Early accounts suggest development around Lake Webster began in the mid to late 1800's. Blatchley (1900) reports that the Yellow Banks was a popular resort area at the time of his work in the area. He also notes the presence of several cottages along the lake's east shore. Modern development around many northern Indiana lakes, including Webster, began in the 1940's and 1950's (Grant, 1999). In 1973, the EPA estimated approximately 295 homes bordering the lake. By 1976, approximately 80% of the shoreline was developed with the remaining 20% being natural wetland (Shipman, 1977). Hippensteel (1989) reported 516 homes bordering Webster in 1980, making it the third most developed shoreline in Koscuisko County behind Lake Wawasee and Lake Tippecanoe. Virtually the entire shoreline including much of the wetland areas had been developed by 1988 (Pearson, 1988).

Today, approximately 832 homes line the shore and channels of Lake Webster while approximately 75 homes exist along the Backwaters shoreline. Of the 832 homes on Webster, 285 are permanent residences, while 547 are used on a seasonal and weekend basis. As is typical of other northern Indiana lakes, the number of permanent residences is increasing as lake residents retire to live at their lake homes fulltime. On the Backwaters, approximately 50% of these homes are permanent and 50% are used seasonally (Dawn Meyers, Lake Webster Association, personal communication). Only a small portion of the Webster northern shoreline is undeveloped and remains as natural wetland. Natural wetland lies along much of the eastern and southern shoreline of the Backwaters.

With residential development of the lake, landscaped lawns and seawalls replace natural shoreline vegetation. Currently, seawalls line approximately 95% of the developed shoreline. Many of these seawalls are made of concrete, however, riprap and rail tie seawalls were also noted along the Webster shoreline. Groomed lawns are maintained behind the seawalls. These seawalls prevent erosion of the shoreline. In areas where seawalls are not present (i.e. most of the Backwaters shoreline), emergent vegetation protects the lakes' shorelines. No significant areas of in-lake shoreline erosion were noted on these lakes.

While seawalls provide erosion control along shorelines, they cannot provide all the functions of a healthy shoreline plant community. Native shoreline communities filter runoff water to the lake, protect the shore from wave action limiting erosion, release oxygen to the water column for use by aquatic biota, and provide food, cover, and spawning/nesting habitat for a variety of fish, waterfowl, insects, mammals and amphibians. Removal of the native plant community removes many of these functions.

Shoreline Best Management Practices (BMPs)
Lakeshore landowners should reduce or eliminate the use of lawn fertilizers. Landowners typically apply more fertilizer to lawns and landscaped areas than necessary to achieve the desired results. Plants can only utilize a given amount of nutrients. Nutrients not absorbed by the plants or soil will run into the lake, providing a nutrient base for plants and algae in the lake. At the very minimum, landowners should follow dosing recommendations on product labels. Landowners should also avoid depositing lawn waste such as leaves and grass clippings in the lake as this adds to the nutrient base in the lakes. This includes disposal of animal waste in the lake. During one lake tour, a resident was observed throwing goose droppings into the lake. This action contributes further nutrients to the water, fertilizing the submerged plants immediately adjacent to the shore.

In addition to reducing the amount of fertilizer used, landowners should apply phosphorus-free fertilizers. Most fertilizers contain both nitrogen and phosphorus. However, the soil usually contains enough natural phosphorus to allow for plant growth. As a consequence, fertilizers with only nitrogen work as well as those with both nutrients. The additional phosphorus cannot be absorbed by the grass or plants and runs off into the lake. Landowners can have their soil tested to ensure that their property does indeed have sufficient phosphorus and no additional phosphorus needs to be added. The local Soil and Water Conservation District or the NRCS can usually provide information on soil testing.

Lake residents should also consider replacing maintained lawns with native vegetation. In those areas that do not have seawalls, rushes (*Juncus* spp.), sedges (*Carex* spp.), pickerel weed (*Pontederia cordata*), arrowhead (*Sagittaria latifolia*), and lizard's tail (*Saururus cernua*) offer an aesthetically attractive, low profile community in wet areas. Behind existing seawalls, a variety of upland forbs and grasses that do not have the same fertilizer/pesticide maintainence requirements as turf grass may be planted in its place. Plantings can even occur in front of existing seawalls. Bulrushes (*Scirpus spp.*) and taller emergents are recommended for this. While not providing all the functions of a native shoreline, plantings in front of seawalls provide fish and invertebrate habitat. In addition, the restoration of native shoreline or the planting of emergents in front of seawalls also discourages Canadian geese. The geese prefer maintained lawns because any predators are clearly visible in lawn areas. Native vegetation is higher in profile than maintained lawns and has the potential to hide predators, increasing the risk for the geese. Partial or full restoration of the native shoreline community with these measures would provide shoreline erosion control and filter runoff to the lakes, thus improving the lake's overall health, without interfering with recreational uses of the lake.

Finally, each lake owner should investigate local drains, roads, parking area, driveways, and rooftops. These drains also contribute to sediment and nutrient loading and thermal pollution. Where possible alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and native plant overland swales.

Aquatic Plant Survey

Heavy vegetation has been a persistent problem on Lake Webster and the Backwaters. A general macrophyte (rooted plant) survey of Lake Webster and the Backwaters was conducted on May 25, 1999. The survey located areas with a high density of submerged and emergent aquatic vegetation in the lake. Due to the limited scope of this LARE study, the survey consisted of a general reconnaissance of the lakes' shorelines. The survey also included two cross-lake transects to inspect off-shore areas. In areas possessing the greatest density of rooted plant growth (based on visual analysis), random rake grabs were performed to determine the species present. No quantitative measures of species abundance or percent cover were recorded. While this methodology has some shortcomings (i.e. may miss less dominant species, provides no quantitative information), it provides good information on the dominant species present and the extent of coverage in the lakes from which general management recommendations can be made.

Beds mapped on Figure 15 reflect areas with high density and high diversity (relative to Lake Webster). Please note however, that much of the shoreline and shallow areas are densely vegetated with Eurasian water milfoil, coontail, and curly leaf pondweed. Based on the two cross lake transects, Eurasian water milfoil, coontail, and curly leaf pondweed dominate nearly all of the areas on the lake less than ten feet in depth (see bathymetric map - Figure 3). Before detailing the results of the macrophyte survey, it may be useful to understand the conditions under which lakes may support macrophyte growth and the roles macrophytes plan in a healthy, functioning lake ecosystem.

Conditions for Growth

Like terrestrial vegetation, aquatic vegetation has several habitat requirements that need to be satisfied in order for the plants to grow or thrive. Aquatic plants depend on sunlight as an energy source. The amount of sunlight available to plants decreases with depth of water as algae, sediment, and other suspended particles block light penetration. Consequently, most aquatic plants are limited to water depths of 5 or 6 feet (1.5 to 1.8 m), but lakes with greater water clarity have a greater potential for plant growth. Some species such as Eurasian water milfoil can grow in up to 12 feet (3 m) of water.

Related to this is the role lake morphology plays in determining a lake's ability to support aquatic vegetation. Shallower lakes often support more aquatic vegetation than deeper lakes. The depth-area curve for Lake Webster (Figure 4) shows that approximately 185 acres (75 ha) is less than 5 feet (1.5 m) in depth and approximately 400 acres (162 ha) is less than 10 feet (3 m) in depth. In other words, approximately 70% of the lake is capable of supporting Eurasian water milfoil. Because the Backwaters is less than 7 feet (2.1 m) in depth throughout its basin, the entire area can support rooted aquatic vegetation.

Aquatic plants also require a steady source of nutrients for survival. Aquatic macrophytes differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes receive most of their nutrients from the sediments via their root systems rather than directly

utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because most nutrients are obtained from the sediments, it does not necessarily follow that lakes with a high input of nutrients from the waterbody's watershed to the water column will automatically have aquatic macrophyte problems. Other factors, such as those listed above, play a role in limiting or promoting the growth of aquatic macrophytes.

The type of substrate present and the forces acting on the substrate affect a lake's ability to support aquatic vegetation. Lakes that have mucky, organic, nutrient rich substrates have an increased potential for plant growth compared to lakes with gravelly, rocky substrates. In addition, lakes that have significant wave action that disturb the bottom sediments have decreased ability to support plants. Disturbance of bottom sediment may decrease water clarity, limiting light penetration or affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether. Boating activity may also affect macrophyte growth by disturbing bottom sediments.

Ecosystem Roles

Aquatic plants are a beneficial and necessary part of healthy lakes. Plants stabilize shorelines holding bank soil with their roots. The vegetation also serves to dissipate wave energy further protecting shorelines from erosion. Plants play a role in a lake's nutrient cycle by uptaking nutrients from the sediments. Like their terrestrial counterparts, aquatic macrophytes produce oxygen which is utilized by the lake's fauna. Plants also produce flowers and unique leaf patterns that are aesthetically attractive.

Emergent and submerged plants provide important habitat for fish, insects, reptiles, amphibians, waterfowl, shorebirds, and small mammals. Fish utilize aquatic vegetation for cover from predators and for spawning and rearing grounds. Aquatic vegetation serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Aquatic plants such as pondweed, coontail, duckweed, water milfoil, and arrowhead, also provide a food source to waterfowl. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

Survey Results

Area 1

Area 1 is a sheltered cove located along the north central shore of the lake. Area 1 exhibits relatively high plant diversity compared to other areas of the lake. Large patches of spatterdock cover most of the cove area. White water lilies are scattered throughout the cove area as well. Dense beds of large leaf pondweed, Illinois pondweed, slender naiad, curly pondweed, and Eurasian water milfoil are located in and around the spatterdock patches. An emergent island dominated by willow and dogwood shrubs is located in the cove. Arrow arum and purple loosestrife were observed around the edge of this island and along the cove's shoreline.

Area 1A

Area 1A is the undeveloped shoreline immediately east of Area 1. Vegetation is this area follows the water depth gradient. Emergents such as cattails, purple loosestrife, and dogwood vegetate the shallowest areas along the shoreline. Spatterdock occupies slightly deeper areas. Submerged beds of Eurasian water milfoil and curly leaf pondweed extend out from the spatterdock. Chara mats were also noted in this area.

Areas 2, 3, and 4

Areas 2, 3, and 4 are largely undeveloped areas of the lake where remnants of the lake's natural shoreline still exist. Areas 2 and 3 are located in the lake's northeast corner, while Area 4 is along the eastern edge of the lake. Like the vegetation in Area 1A, vegetation in these areas follow a water depth gradient. Cattails and purple loosestrife vegetate the shoreline in these areas. Patches of spatterdock occupy slightly deeper water close to the shoreline. Eurasian water milfoil, curly leaf pondweed, and coontail dominate the submerged beds. Chara mats dominate some of the shallow water in these areas.

Area 5

Area 5 refers to Webster Bay. The shallow protected water in Webster Bay makes the area conducive to plant growth. Large patches of spatterdock float along the eastern edge of the bay. At the time of inspection, some of these patches extended to the center of the bay. Smaller patches of spatterdock were noted along the western edge of the bay. In deeper water, dense beds of coontail, Eurasian water milfoil, and curly leaf pondweed dominate. Several species of duckweed were observed in the bay as well.

Area 6

Area 6 is located at the mouth of Webster Bay. This area is typical of many areas on the lake that are protected from wind and wave energy. Spatterdock patches extend out from the seawall in this cove, while dense beds of Eurasian water milfoil, coontail, and curly leaf pondweed surround the spatterdock.

Area 7

Area 7 is located in the southwest corner of the lake. This area supports a slightly more diverse plant community than other areas of the lake. Species observed in Area 7 include whorled water milfoil, Eurasian water milfoil, elodea, coontail, curly leaf pondweed and spatterdock. It should be noted that whorled water milfoil is a state threatened species. (According to the Indiana classification scheme, plants known to occur at six to ten sites in the state fall under the "threatened" category.)

While these seven areas form the densest and most diverse beds of aquatic macrophytes, dense macrophyte growth was also observed along much of the shoreline and in areas less than 12 feet deep. Eurasian water milfoil, curly leaf pondweed, and coontail beds typically dominate these areas. In addition to these dominants, naiads, Illinois pondweed, Varian grassleaf pondweed (Illinois state endangered), whorled water milfoil, and northern water milfoil were observed. Thick chara mats excluded submerged vegetation in a few spots as well. Appendix 6 provides a complete list of macrophytes found in this survey as well as some historical surveys on Lake Webster.

The Backwaters

Emergents such as cattails, hibiscus, bulrush, arrow arum, and burreed dominate the undeveloped shoreline. Patches of spatterdock and white water lilies occupy shallow water closer to the shoreline, particularly in the undeveloped portions of waterfront. Dense beds of Eurasian water milfoil, coontail, and curly leaf pondweed infest deeper areas of the Backwaters. Several genera of duckweed including *Lemna* spp., *Wolfia* spp., and *Spiradella elirasia* form free floating mats on the water. It is likely that the untreated milfoil in the Backwaters will re-infest Lake Webster in the next few years.

Discussion

In general, Eurasian water milfoil, curly leaf pondweed, and coontail dominate both Lake Webster and the Backwaters. Eurasian water milfoil and curly leaf pondweed are not native to Indiana lakes. These species typically grow in dense mats excluding other plants and offering little if any habitat potential for aquatic fauna. Aerial photographs taken by lake residents in 1998 show the Eurasian water milfoil exhibiting this behavior. Color photographs of the lake appeared green from the density of milfoil in the lake. Lake Webster's morphometry, with extensive shallow areas, makes the lake particularly susceptible to rooted aquatic plant growth.

While curly leaf pondweed and Eurasian water milfoil dominate the lake macrophyte communities, they have not completely eliminated native plants. Spatterdock, pickerel weed, coontail, and pondweeds are typical natives in the Northern Lakes Natural Region (Homoya et al., 1985) Healthy individuals of these species were noted in Lake Webster. In addition, patches of large-leaved pondweed, which provides excellent fish habitat (Curtis, 1998), exist in certain sections of the lake. Lastly, whorled milfoil (*Myriophyllum verticillatum*) which is a state threatened species was observed in Lake Webster.

It is important to note that the presence of curly leaf pondweed and Eurasian water milfoil is typical for northern Indiana lakes. These species were observed in every lake in Kosciusko County in 1997 (White, 1998a). Moreover, their absence was only documented in seven lakes in 15 of the northern counties in Indiana. These 15 counties include all of the counties in northeastern Indiana where most of Indiana's natural lakes are located. Of the northern lakes receiving permits to treat aquatic plants in 1998, Eurasian water milfoil was listed as the primary target in those permits (White, 1998b).

Basin morphology contributes to the abundant macrophyte growth observed in both lakes. As noted early, Lake Webster consists of several deeper basin joined by shallower water. Approximately 70% of the lake is less than 10 feet deep, providing excellent habitat potential for rooted plants. The shallowness of the Backwaters area combined with the influx of nutrients from an agricultural watershed create ideal conditions for macrophyte growth as well. Because the maximum depth is 7 feet (2.1m), light penetration is possible throughout the Backwaters area. During the macrophyte survey, vegetation was observed throughout the lake.

The population of duckweed in the Backwaters area has received much attention in the local media. Backwaters residents have reported mats of duckweed so thick that they give the water a green appearance. The DNR reports suggest the duckweed problem has grown worse over the years as native lily pads that once held the duckweed in place were removed from the Backwaters. In addition, changes made to the bridge structure between Lake Webster and the Backwaters may have altered the flow between the lakes trapping the duckweed in the Backwaters area.

Duckweeds are native plants that do not typically dominate lakes as has been reported on the Backwaters. However, its presence in the Backwaters is not wholly unexpected. Duckweed is an indicator of high nutrient loads. The Backwaters' large agricultural watershed coupled with its organic substrate provide a regular influx of nutrients to the lake.

<u>Aquatic Plant Management</u>

Based on the results of this survey and evidence from previous studies, development of an aquatic plant management plan is needed for Lake Webster and the Backwaters area. Such a plan should target nuisance populations such as the Eurasian water milfoil and duckweed, while protecting native pondweeds. The plan should set reasonable reduction goals, acknowledging that the basin morphology of the lakes predispose them to aquatic plant growth. The plan should also recognize vital roles performed by aquatic plants in a healthy lake ecosystem. In other words, complete eradication of aquatic plants is neither desired nor feasible.

Prior to this study, the Webster Lake Association had selected chemical control as their method for managing their lake's vegetation. Anecdotal reports from Aquatic Control representatives and lake residents suggest the Sonar treatment was successful, and both parties are hoping to obtain multi-year control from the 1999 application. This chemical treatment should not be considered a long-term restoration technique. However, in light of the time, effort, and money already invested in this control program, the lake association should continue monitoring the results of the treatment. Any future management plan should also recognize the current commitment to this management technique.

Good aquatic plant management plans often employ a combination of techniques, utilizing different ones in different locations on the lake, to achieve their goals. Lake users' needs, plant species, cost, and other factors affect the selection of specific techniques for specific locations.

Not all techniques are suitable or even feasible for a given lake. The following is a brief summary of the available techniques. It is intended to inform lake residents of the options available for aquatic plant management and serve as a starting point for the development of a comprehensive aquatic plant management plan for the lakes. It is not an aquatic plant management plan itself.

<u>Chemical control</u>

Herbicides are the most traditional means of controlling aquatic vegetation. Herbicides vary in their specificity to given plants, method of application, residence time in the water and the use restrictions for the water during and after treatments. Herbicides (and algalcides; chara is an algae) that are non-specific and require whole lake applications to work are generally not recommended. Such herbicides can kill non-target plant and sometimes even fish species in a lake. Costs of an herbicide treatment vary from lake to lake depending upon the type of plant species present in the lake, the size of the lake, access availability to the lake, the water chemistry of the lake, and other factors. Typically, in northern Indiana costs for treatment range from $275 to $300 per acre ($680 to $750 per hectare, Jim Donahoe, Aquatic Weed Control, personal communication).

While providing a short-term fix to the nuisances caused by aquatic vegetation, chemical control is not a lake restoration technique. Herbicide and algalcide treatments do not address the reasons why there is an aquatic plant problem and treatments need to be repeated each year to obtain the desired control. In addition, some studies have shown that long-term use of copper sulfate (algalcide) has negatively impacted some lake ecosystems. Such impacts include an increase in sediment toxicity, increased tolerance of some algae species, including some blue green (nuisance) species, to copper sulfate, increased internal cycling of nutrients and some negative impacts on fish and other members of the food chain (Hanson and Stefan, 1984 cited in Olem and Flock, 1990).

Past use on Lake Webster

Chemical control has been used in the past as the principle means of aquatic plant control in Lake Webster. In response to heavy Eurasian water milfoil cover, the Lake Webster Association voted to treat their lake with Sonar (fluridone). Aquatic Control from Seymor, Indiana treated the lake with three applications in the late spring/early summer of 1999. Bob Johnson (Aquatic Control) and many of the lake residents report excellent results from the treatment (personal communication). While the initial results appear encouraging and visual inspection of the lake suggests that last year’s treatment may provide multi-year control, more time is needed to determine the effectiveness and length of macrophyte control in Webster.

Effectiveness

Table 12 is a guide for common herbicides and their effectiveness in treating the dominant macrophytes found in Indiana lakes. This table is general in nature. While the table rates the chemical as effective vs. non-effective, some chemicals are obviously more effective than others.

The effectiveness of any chemical often depends upon the water chemistry of the lake to which it is applied. Any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of a targeted lake. In addition, application of a chemical herbicide may require a permit from the Indiana Department of Natural Resources, depending on the size and location of the treatment area. Information on permit requirements is available from the DNR Division of Fish and Wildlife or conservation officers.

Table 12: Common Herbicides and Their Effectiveness

	Diquat	**Endothal**	**2,4 D**	**Fluridone**
Eurasian water milfoil	M	M	E	E
Curly leaf pondweed	E	E	N	E
Other pondweeds	E	E	-	E*
Coontail	E	E	E	E
Elodea	E	M	N	E
Naiads	E	E*	E*	M

* Depends on species
E = effective
N = non effective
M = mixed results
Table based on information from Olem and Flock, 1990, Westerdahl and Getsinger, 1988, Pullman, 1992 and SePro, 1999.

Mechanical Harvesting

Harvesting involves the physical removal of vegetation from lakes. Harvesting should be viewed as a short-term management strategy. Like chemical control, harvesting needs to be repeated yearly and sometimes several times within the same year. (Some carry-over from the previous year has occurred in certain lakes.) Despite this, harvesting is often an attractive management technique because it can provide lake users with immediate access to areas and activities that have been affected by excessive plant growth. Mechanical harvesting is also beneficial in situations where removal of plant biomass will improve a lake's water chemistry. (Chemical control leaves dead plant biomass in the lake to decay and use up valuable oxygen.)

Macrophyte response to harvesting often depends upon the species of plant and particular way in which the management technique is performed. Pondweeds, which rely on sexual reproduction for propagation, are managed well through harvesting. However many harvested plants, especially milfoil, can re-root or reproduce vegetatively from the cut pieces left in the water. Plants harvested several times during the growing season, especially late in the season, often grow more slowly the following season (Cooke et al., 1993). Harvesting plants at their roots is usually more effective than harvesting higher up on their stems (Olem and Flock, 1990). This is especially true with Eurasian water milfoil and curly leaf pondweed. Benefits are also derived if the cut plants and the nutrients they contain are removed from the lake. Harvested vegetation that is cut and left in the lake ultimately decomposes, contributing nutrients and consuming oxygen.

The cost of the harvester is typically the largest single outlay of money. Depending upon the capacity of the harvester, costs can range from $3,500 to over $100,000 (Cooke et al., 1993). Other costs associated with harvesting include labor, disposal site availability and proximity, amortization rate, size of lake, density of plants, reliability of the harvester, and other factors. Depending upon the specific situation, harvesting costs can range up to $650 per acre ($1,600 per hectare, Prodan, 1983; Adams, 1983). Estimated costs of the mechanical harvesting program at Lake Lemon in Bloomington, Indiana averaged $267 per acre ($659 per hectare, Zogorski et al., 1986). In general, however, excluding the cost of the machine, the cost of harvesting is comparable to that for chemical control (Cooke et al., 1993, Olem and Flock, 1990). Hand-harvesting equipment is also available for smaller areas around piers at a cost of from $50-$1,500 (McComas, 1993).

Drawdown

Lake level drawdown can be used as a macrophyte control technique or as an aid to other lake improvement techniques. This technique requires the ability to discharge water from a lake through an outlet structure or dam. Drawdown can be used to provide access to dams, docks, and shoreline stabilizing structures for repairs; to allow dredging with conventional earthmoving equipment; and to facilitate placement of sediment covers.

As a macrophyte control technique, drawdown is recommended in situations where prolonged (one month or more) dewatering of sediments is possible under conditions of severe heat or cold and where susceptible species are the major nuisances. Eurasian water milfoil control for example, apparently requires three weeks or longer of dewatering prior to a one-month freezing period (Cooke, 1980). Cooke (1980) classifies 63 macrophyte species as decreased, increased, or unchanged after drawdown. One must note the presence of resistant species as well as susceptible species, since resistant species can experience a growth surge after a successful drawdown operation.

Macrophyte control during drawdown is achieved by destroying seeds and vegetative reproductive structures (e.g., tubers, rhizomes) via exposure to drying or freezing conditions. To do so, complete dewatering and consolidation of sediments is necessary. Dewatering may not be possible in seepage lakes.

There are a number of other benefits to lakes and reservoirs from drawdown. Game fishing often improves after a drawdown because it forces smaller fish (bluegill) out of the shallow areas and concentrates them with the predators (bass). This decreases the probability of stunted fish and increases the winter growth of the larger game fish. Drawdown has also been used to consolidate loose, flocculent sediments that can be a source of turbidity in lakes. Dewatering compacts the sediments, and they remain compacted after reflooding (Born et al. 1973 and Fox et al. 1977).

A final consideration in implementation of lake level drawdown is season; winter or summer are usually chosen because they are most severe. According to Cooke (1980), "it is not clear whether drawdown and exposure of lake sediments to dry, hot conditions is more effective than exposure to dry, freezing conditions." One factor to consider is which season is most rigorous. Advantages of winter drawdown include less interference with recreation, ease of spring versus autumn refill, and no invasion of terrestrial plants. Sediment dewatering is easier in summer. One drawback to a winter drawdowns is the potential for fish kills. IDNR biologists note that this is of concern for Lake Webster (Pearson, 2000).

In Murphy Flowage, a 180-acre (73 ha) reservoir in Wisconsin, a five foot drawdown from mid-October to March greatly reduced the presence of aquatic macrophytes the following growing season. Milfoil was reduced from 20 to <2.5 acres (8 ha to <1 ha), spatterdock was reduced from 42 to 12.5 acres (17 ha to 5 ha), and pondweeds were reduced from 114 to 7.5 acres (46 ha to 3 ha) (Beard 1973).

Drawdowns are not possible on all lakes. In lakes and reservoirs that do not have legal lake levels, manipulation of water level is possible without obtaining permission from regulatory agencies. Any effort to raise or lower the lake level requires that the legal level be changed. This process can be quite time consuming taking up to a year for a decision to be made. In addition, drawdowns are not physically practical on lakes that lack water control structures. On lakes where drawdowns are feasible, however, they offer a low cost management technique that does not require the introduction of chemicals or machinery.

<u>Biological Control</u>

Grass carp

Grass carp are the most well known species used for biological control of aquatic plants. Grass carp are an exotic fish species brought to this country from Malaysia. These carp feast on a wide range of aquatic weeds; *Elodea* spp. and pondweeds are among their favorites. Unfortunately, grass carp do not like milfoil and will only eat milfoil when its favorite foods are depleted. Over the course of time, grass carp typically will devour all the plants in a lake, leaving none for fish habitat or bank/substrate stabilization. In addition, grass carp may negatively alter resident fish communities, increase nutrient release from sediments promoting algal blooms and increase the turbidity of lakes. For these reasons, the use of grass carp in public waters is banned in 18 states including Indiana. Carp stocked in private ponds must be certified as genetically triploid (incapable of reproduction) and must have no possible access to other waterways.

Insects

The use of specific insect species in controlling aquatic plant growth has been investigated as well. Much of this research has concentrated on aquatic plants that are common in southern lakes such as alligator weed, hydrilla and water hycinth. Cooke et al. (1993) also points to four different species that may reduce Eurasian water milfoil infestations: *Triaenodes tarda*, a caddisfly, *Cricotopus myriophylii*, a midge, *Acentria nivea*, a moth and *Litodactylus leucogaster*, a weevil.

Eurasian water milfoil
Recent research suggests another alternative: *Euhrychiopsis lecontei*, a weevil. *E. lecontei* has been implicated in a reduction of Eurasian water milfoil in several Northeastern and Midwestern lakes (EPA, 1997). *E. lecontei* weevils reduce milfoil biomass by two means: one, both adult and larval stages of the weevil eat different portions of the plant and two, tunneling by weevil larvae causes the plant to lose buoyancy and collapse, limiting its ability to reach sunlight. Techniques for rearing and releasing the weevil in lakes have been developed and under appropriate conditions, use of the weevil has produced good results in reducing Eurasian water milfoil.

Cost effectiveness and environmental safety are among the advantages to using the weevil rather than traditional herbicides in controlling Eurasian water milfoil (Christina Brant, EnviroScience, personal communication). Cost advantages include the weevil's low maintenance and long-term effectiveness versus the annual application of an herbicide. In addition, use of the weevil does not have use restrictions that are required with some chemical herbicides. Use of the weevil has a few drawbacks. The most important one to note is that reductions are seen over the course of several years, however, so lake residents need to be patient. Because the Backwaters possesses some site-specific conditions that increase the likelihood of favorable results, an *E. lecontei* release in the Backwaters should be explored as a method to reduce the Eurasion water milfoil in the lake.

Purple loosestrife
Biological control may also be possible for controlling the growth and spread of the emergent purple loosestrife. Like Eurasian water milfoil, purple loosestrife is an aggressive non-native species. Once purple loosestrife becomes established in an area, the species will readily spread and take over the habitat, excluding many of the native species, which are more valuable to wildlife. Conventional control methods including mowing, herbicide applications, and prescribed burning have been unsuccessful in controlling purple loosestrife.

Some control has been achieved through the use of several insects. A pilot project in Ontario, Canada reported a decrease of 95% of the purple loosestrife population from the pretreatment population (Cornell Cooperative Extension, 1996). Four different insects were utilized to achieve this control. These insects have been identified as natural predators of purple loosestrife in its native habitat. Two of the insects specialize on the leaves and defoliate the plant (*Gallerucella calmariensis* and *G. pusilla*), one specializes on the flower, while one eats the roots of the plant (*Hylobius transversovittatus*). Releases in Indiana to date have had mixed results. After six years at Fish Lake in LaPorte County, the loosestrife is showing signs of deterioration.

Like biological control of Eurasian water milfoil, use of purple loosestrife predators offers a cost-effective means for achieving long-term control of the plant. Complete eradication of the plant cannot be achieved through use of a biological control. Insect (predator) populations will follow the plant (prey) populations. As the population of the plant decreases, the population of the insect will also decrease since their food source is decreasing.

Bottom covers

Bottom shading by covering bottom sediments with fiberglass or plastic sheeting materials provides a physical barrier to macrophyte growth. Buoyancy and permeability are key characteristics of the various sheeting materials. Buoyant materials (polyethylene and polypropylene) are generally more difficult to apply and must be weighted down. Sand or gravel anchors can act as substrate for new macrophyte growth, however. Materials must be permeable to allow gases to escape from the sediments; gas escape holes must be cut in impermeable liners. Commercially available sheets made of fiberglass-coated screen, coated polypropylene, and synthetic rubber are non-buoyant and allow gases to escape, but cost more (up to $66,000 per acre or $163,000 per hectare for materials, Cooke and Kennedy, 1989). Indiana regulations specifically prohibit the use of bottom covering material as a base for beaches.

Due to the prohibitive cost of the sheeting materials, sediment covering is recommended for only small portions of lakes, such as around docks, beaches, or boat mooring areas. This technique may be ineffective in areas of high sedimentation, since sediment accumulated on the sheeting material provides a substrate for macrophyte growth. The IDNR requires a permit for any permanent structure on the lake bottom, including anchored sheeting.

Dredging

Dredging is occasionally used as a means to control aquatic plant growth. Dredging may control aquatic vegetation by two means. First, it removes aquatic vegetation. Second, it may prevent the re-establishment of vegetation by removing the substrate in which vegetation flourished and deepening the lake to a depth at which the sunlight penetration may be too limited or water pressure may be too great to allow for plant growth. Any dredging activities in a fresh water public lake will require permits from the Corps of Engineers, the Indiana Department of Environmental Management (IDEM), and IDNR. Dredging operations are fairly costly with prices ranging from $15,000 to $20,000 per acre ($37,000 to $49,400 per hectare, Jeff Krevda, Dredging Technologies, personal communication). This estimate excludes the cost of transportation to a disposal site and purchasing the disposal site if one is not available for free.

Dredging has several negative ecological impacts associated with it. For example, habitat for many aquatic insects (the macrophytes and top portion of the lake sediment) is removed along with the insects. These insects serve as an important food source to fish, and their removal may harm a lake's fishery. In addition, mechanical dredging resuspends nutrient rich sediments which could lead to algae blooms. Because of these reasons and given the amount of material that would have to be removed in order to achieve the desired effect in Lake Webster or the Backwaters area, dredging is not recommended as a cost effective means of aquatic plant control. However, limited dredging in select areas as a means to control phosphorus release from bottom sediments could be considered. A detailed feasibility study would be required to examine the potential for such a project.

Lake and Stream Sampling

Methods

The water sampling and analytical methods used for Lake Webster and the Backwaters area were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected for various parameters on August 12, 1999 from the surface waters (*epilimnion*) and from the bottom waters (*hypolimnion*) of the lake. These parameters include pH, alkalinity, conductivity, total suspended solids, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and organic nitrogen.

In addition to these parameters, several other measurements of lake health were recorded. Secchi disk, light transmission, and oxygen saturation are single measurements. Dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. Chlorophyll was determined only for an epilimnetic sample. A tow to collect plankton was made from the 1% light level to the water surface.

The major streams flowing into and out of Lake Webster and the Backwaters area were sampled once during this project at less than base flow conditions on 8/12/99 and once after a storm runoff event on 4/21/00. The area was experiencing a drought during late summer 1999. As a result, discharge could not be measured during base flow sampling. Storm sampling followed a major storm on 4/20/00. Two to five inches (5 to 13 cm) of rain were reported for Koscuisko County that day. Site 5 was not sampled during the storm event. The sampling locations included (Figure 16):

Site 1	Tippecanoe River outlet at SR 13
Site 2	Gaff Ditch at County Road 450 North
Site 3	Tippecanoe River at SR 5
Site 4	Ditch at County Road 675 North and County Road 925 East
Site 5	Ditch at County Road 700 North

The comprehensive evaluation of lakes and streams requires collecting data on a number of different, and sometimes hard-to-understand, water quality parameters. Some of the more important parameters that were analyzed include:

Phosphorus. Phosphorus is an essential plant nutrient, and the one that most often controls aquatic plant (algae and macrophyte) growth. It is found in fertilizers, human and animal wastes, and yard waste. There are few natural sources of phosphorus to lakes and there is no atmospheric (vapor) form of phosphorus. For this reason, phosphorus is often a ***limiting nutrient*** in lakes. This means that the relative scarcity of phosphorus in lakes may limit the ultimate growth and production of algae and rooted aquatic plants. Therefore, lake management efforts often focus on reducing phosphorus inputs to lakes because: (a) it can be managed and (b) reducing phosphorus can reduce algae production. Two common forms of phosphorus are:

Soluble reactive phosphorus (SRP) – SRP is dissolved phosphorus readily usable by algae. SRP is often in very low concentrations in lakes with dense algae populations where it is tied up in the algae themselves. SRP may be released from storage in sediments when dissolved oxygen is lacking.

Total phosphorus (TP) – TP includes dissolved and particulate phosphorus. TP concentrations greater than 0.04 mg/L (or 40 µg/L) can cause algal blooms.

Nitrogen. Nitrogen is an essential plant nutrient found in fertilizers, human and animal wastes, yard waste, and the air. About 80% of the air is nitrogen gas. This nitrogen can diffuse into water where it can be "fixed", or converted, by blue-green algae for their use. Nitrogen can also enter lakes and streams as inorganic nitrogen and ammonia. Because of this, there is an abundant supply of available nitrogen to lakes. The three common forms of nitrogen are:

Nitrate (NO_3) – Nitrate is dissolved nitrogen that is converted to ammonia by algae. It is found in lakes when dissolved oxygen is present, usually the surface waters.

Ammonia (NH_4) – Ammonia is dissolved nitrogen that is the preferred form for algae use. Bacteria produce ammonia as they decompose dead plant and animal matter. Ammonia is found where dissolved oxygen is lacking, often in the hypolimnia of eutrophic lakes.

Organic Nitrogen (Org N) – Organic nitrogen includes nitrogen found in plant and animal materials. It may be in dissolved or particulate form. In analytical procedures, total Kjeldahl nitrogen (TKN) is often analyzed. Organic nitrogen is TKN minus ammonia

Dissolved Oxygen (D.O.). D.O. is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 parts per million (ppm) of D.O. Cold water fish such as trout and cisco generally require higher concentrations of D.O. than warm water fish such as bass or bluegill. D.O. affects a variety of chemical reactions in water. For example, the lack of D.O. near the bottom sediments may allow dissolved phosphorus (SRP) to be released from the sediments into the water. If less than 50% of a lake's water column has oxygen, greater hypolimnetic concentrations of SRP and ammonia are common as well. D.O. enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with D.O. Dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Secchi Disk Transparency. Secchi disk transparency is the depth to which the black & white Secchi disk can be seen in the water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural lands and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds.

Light Transmission. Similar to the Secchi disk transparency, this measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the water column. Another important light transmission measurement is the 1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. This is considered the lower limit of algal growth.

Plankton. Plankton are important members of the aquatic food web. They include algae (microscopic plants) and zooplankton (tiny shrimp-like animals that eat algae). Plankton density is determined by filtering water through a net having a very fine mesh (63 micron openings = 63/1000 millimeter). The plankton net is towed up through the water column from the one percent light level to the surface. Of the many different algal species present in the water, the blue-green algae are of particular interest. Blue-green algae are those that most often form nuisance blooms; their dominance in lakes may indicate poor water conditions.

Chlorophyll *a*. The plant pigments of algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass.

Lake Sampling Results

Results of the Lake Webster and the Backwaters area water characteristics assessment are included in Tables 13 and 14 and Figures 17 and 18.

Table 13. Water Quality Characteristics of Lake Webster, 8/12/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.5	7.5	-
Alkalinity	182 mg/L	194 mg/L	-
Conductivity	441 µmhos	358 µmhos	-
Total Suspended Solids	1.6 mg/L	3.27 mg/L	-
Secchi Disk Transp.	3.9 feet	-	6
Light Transmission @ 3 ft	25%	-	4
1% Light Level	10 feet	-	-
Total Phosphorus	0.045 mg/L	0.269 mg/L	3
Soluble Reactive Phos.	0.02 mg/L	0.226 mg/L	4
Nitrate-Nitrogen	<0.022 mg/L	<0.022 mg/L	0
Ammonia-Nitrogen	<0.018 mg/L	2.0 mg/L	4
Organic Nitrogen	0.95 mg/L	0.953 mg/L	3
Oxygen Saturation @ 5 ft.	85%	-	0
% Water Column Oxic	38%	-	3
Plankton Density	3710 per L	-	1
Blue-Green Dominance	No	-	0
Chlorophyll *a*	8.67 µg/L	-	
		TSI Score	28

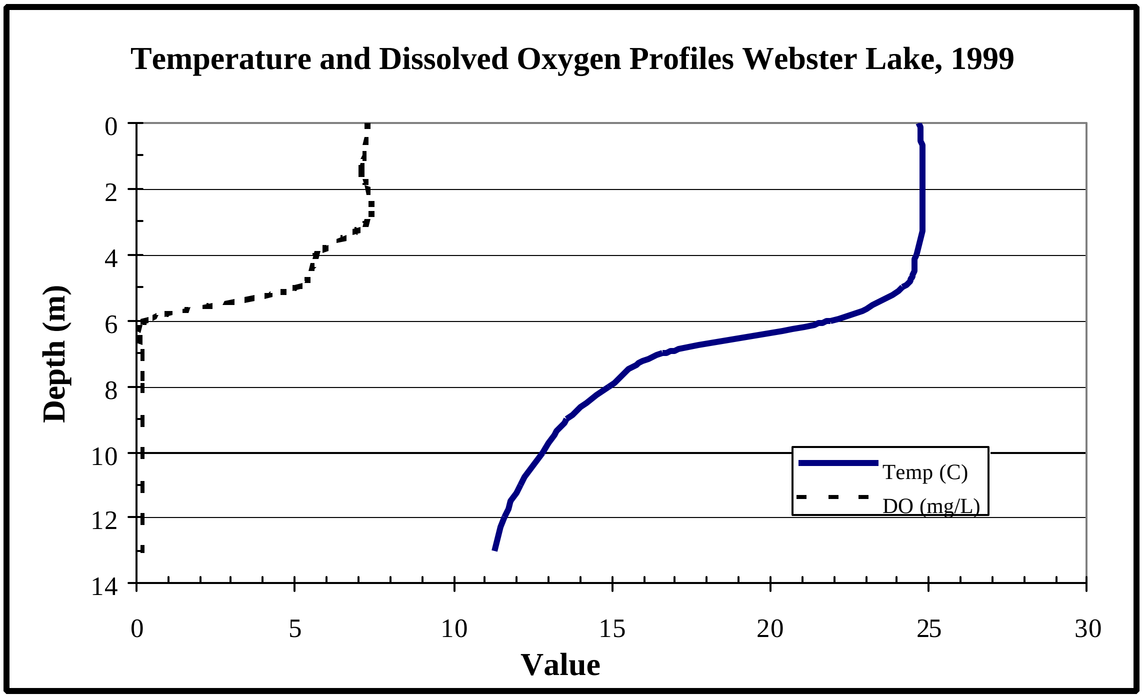


Figure 17. Temperature and Dissolved Oxygen Profiles of Lake Webster on 8/12/99.

Table 14. Water Quality Characteristics of Backwaters, 8/12/99.

Parameter	Epilimnetic Sample (1m)	Hypolimnetic Sample (3m)	Indiana TSI Points (based on mean values)
pH	7.75	-	-
Alkalinity	224.0 mg/L	-	-
Conductivity	500 µmhos	-	-
Secchi Disk Transp.	1.6 feet	-	6
Light Transmission @ 3 ft	5%	-	4
1% Light Level	5 feet	-	-
Total Phosphorus	0.144 mg/L	-	3
Soluble Reactive Phos.	0.036 mg/L	-	0
Nitrate-Nitrogen	0.004 mg/L	-	0
Ammonia-Nitrogen	0.018 mg/L	-	0
Organic Nitrogen	1.726 mg/L	-	2
Oxygen Saturation @ 5 ft.	27%	-	0
% Water Column Oxic	100%	-	0
Plankton Density	3379 per L	-	1
Blue-Green Dominance	No	-	0
Chlorophyll-a	25.81 µg/L	-	-
		TSI score	16

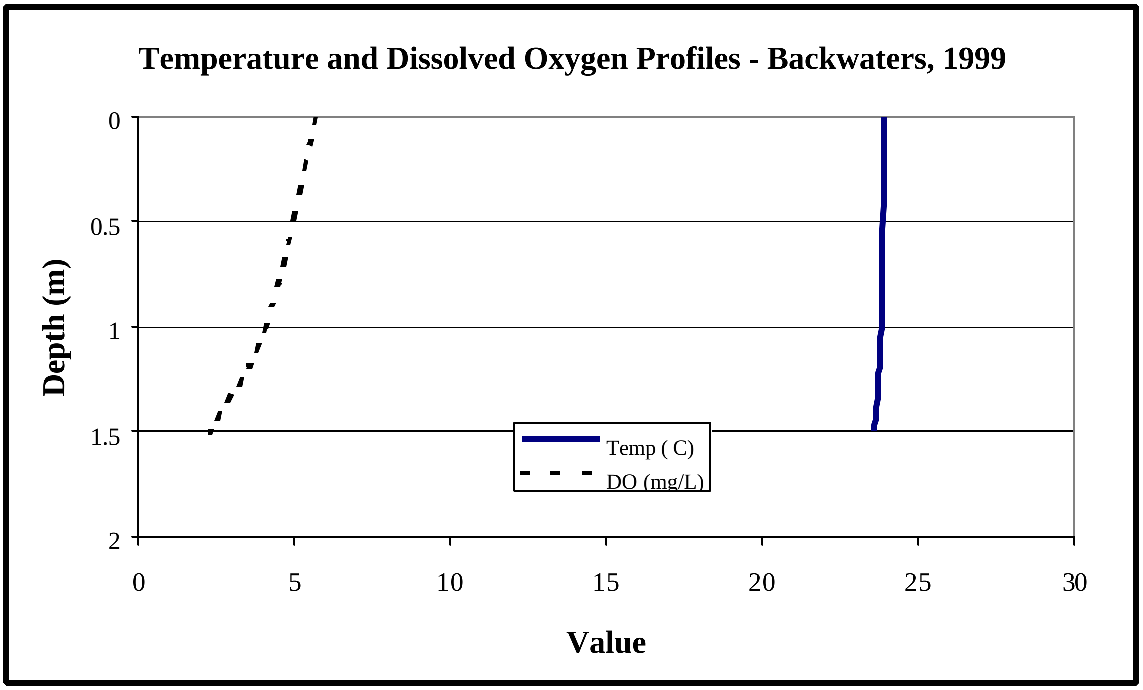


Figure 18. Temperature and Dissolved Oxygen Profiles of the Backwaters area on 8/12/99.

Temperature and oxygen profiles for Lake Webster show that the lake was stratified at the time of sampling (Figure 17). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed surface waters (*epilimnion*) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion*. At the time of sampling, the epilimnion was confined to the upper 16 feet (5 m) of water. The sharp decline in temperature between 16 and about 23 feet (5 and 7 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 26 feet (8 m). Temperature and oxygen profiles for Backwaters show that the lake was not stratified at the time of sampling (Figure 18).

Lake Webster has an expected oxygen profile. The epilimnion is nearly saturated with oxygen with concentrations still has high has 95.4% saturation at 16 feet (5 m). There is a slight increase in D.O. between 6.5 and 10 feet (2 and 3 m). This likely due to a higher density of photosynthesizing algae at this depth. In some lakes, algae may concentrate in the upper metalimnion where higher water density slows their sinking, but where there is still sufficient light for photosynthesis and nutrients may be more available due to 'leakage' from the hypolimnion. Below this point, oxygen concentrations decline rapidly as bacteria decompose algae as they settle down through the water column. This type of oxygen profile is common in lakes that are clear enough to allow light to penetrate that deep. Below 19 feet (6 m), all remaining oxygen is consumed producing an anoxic environment.

Water quality data for Lake Webster and the Backwaters area are presented in Tables 12 and 13 respectively. Phosphorus and nitrogen are the primary plant nutrients in lakes. Concentrations of these nutrients are relatively low in the surface waters of the lake. Higher concentrations of phosphorus in the hypolimnion indicate that phosphorus is being liberated from the sediments due to the anoxic, chemically reducing conditions there. In the Backwaters area, nutrient concentrations are similar to the surface water of Lake Webster. In Lake Webster, there is a detectable amount of soluble reactive phosphorus in the epilimnion as well as in the hypolimnion. This is the form of phosphorus that is available for rooted plant and algae uptake. Because ammonia is a by-product of the decomposition of organic matter, ammonia concentrations are also higher in the hypolimnion where decomposition rates are high and where ammonia is not oxidized.

Alkalinity is a measure of the water's ability to resist change in pH, or acid content. It is also referred to as acid neutralizing capacity or buffering capacity. This buffering action is important because it ensures a relatively constant chemical and biological environment in lakes. Alkalinity is determined largely by the availability and chemistry of carbonate in water. Sources of carbonate to natural waters include limestone (calcium carbonate) and carbon dioxide. The high alkalinity concentrations observed in both Lake Webster and the Backwaters area indicate that they are well-buffered systems. Values of pH are consistent throughout the epilimnion and the hypolimnion in Lake Webster.

The 1% light level, which limnologists use to determine the lower limit at which photosynthesis can occur, extended to a depth of 10 feet (3.05 meters) in Lake Webster and to a depth of 5 feet (1.5 meters) in Backwaters. This 1% light depth probably results from the low total suspended solids and plankton concentrations. Referring to Lake Webster’s depth-volume curve (Figure 5), approximately 58% of the water volume in the lake has sufficient light to support algae. Approximately 95% of the water volume in the Backwaters has sufficient light to support algae.

Stream Sampling Results

Base flow results

Base flow stream sampling results are given in Table 15. Base flow sampling included measurements of common chemical and physical characteristics as well as nutrient and suspended sediment levels. There are two useful ways to report water quality data in flowing water. *Concentrations* describe the mass of a particular material contained in a unit of water, for example milligrams of phosphorus per liter (mg/L). *Mass loading* on the other hand describes the mass of a particular material being carried in the stream per unit of time. For example, a high concentration of phosphorus in a stream with very little flow can deliver a smaller total amount of phosphorus to the lake than will a stream with a low concentration of phosphorus but a high flow of water. It is the total amount (mass) of phosphorus, solids and bacteria actually delivered to the lake that are most important when considering the effects of these materials on a lake. Because there was so little water flowing in the streams at the time of base flow sampling, discharge was not measured. Thus, only concentrations are reported.

Table 15. Water Quality Characteristics of Webster Stream Inlets and Outlets, 8/12/99.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5
pH	7.8	7.3	7.7	7.7	7.45
Alkalinity (mg/L)	185.9	299.6	200.2	242.0	262.1
Conductivity (μmhos)	439	539	485	395	488
Temperature (^oC)	22.4	19.0	22.5	18.4	20.0
Dissolved Oxygen (mg/L)	3.9	0.5	5.0	5.3	0.4
Total Phosphorus (mg/L)	0.034	0.623	0.123	0.096	0.060
Soluble Reactive Phos. (mg/L)	0.042	0.321	0.079	0.039	0.036
Nitrate-Nitrogen (mg/L)	0.078	0.028	0.024	0.806	0.013
Ammonia-Nitrogen (mg/L)	0.069	0.076	0.017	0.396	0.015
Organic Nitrogen (mg/L)	0.702	1.237	0.90	1.431	1.195
Total Suspended Solids (mg/L)	2.20	18.89	3.14	13.00	6.40

During base flow conditions, temperatures in the streams varied from 18.4 ^oC to 22.5 ^oC. Those streams with cooler temperatures likely have a greater proportion of groundwater flowing in them. Stream temperatures are generally cooler than lake temperatures due to the groundwater influence and because there is less solar warming of shaded stream water.

Dissolved oxygen (D.O.) concentrations vary from 0.4 ppm (mg/L) to 5.3 ppm. Because D.O. varies with temperature (cold water can contain more oxygen than warm water), it is more relevant to consider D.O. saturation values. This refers to the amount of oxygen dissolved in water compared to the maximum possible when the water is saturated with oxygen. The saturation value of water at 20 ^oC is 9.1 ppm. All of the stream dissolved oxygen concentrations are less than this value, indicating that: a) decomposition processes within the streams consume oxygen more quickly than it can be replaced by diffusion from the atmosphere, and b) flow in the streams is not turbulent enough to entrain sufficient atmospheric oxygen. Since the stream discharges at the time of sampling were somewhat less than base flow, the low oxygen concentrations are not unexpected.

Alkalinity is lowest in the streams during storm events because during periods of high runoff, the alkalinity is diluted by rainwater and the runoff water moves across carbonate-containing bedrock materials so quickly that little carbonate is dissolved to add additional alkalinity. During low discharges, alkalinity is usually high because it picks up carbonates from the bedrock. This accounts for the high alkalinity measurements recorded during low flow in Lake Webster's streams.

Total phosphorus concentrations are highest in Gaff Ditch (Site 2). The Tippecanoe River (Site 3) had the next highest phosphorus concentration. These could be significant sources of phosphorus loading to Lake Webster, depending on the volume of water discharged from these streams. Nitrogen concentrations in the streams are very different from the patterns observed for phosphorus. The Ditch at County Road 675 North (Site 4) has the highest concentrations of total nitrogen followed by Site 2. Gaff Ditch and the ditch at County Road 675 North (Site 2 & Site 4) had the highest concentrations of total suspended solids during base flow.

Storm flow results
Storm flow stream sampling results are given in Table 16. For laboratory data sheets, please see Appendix 7.

Table 16. Water Quality Characteristics of Webster Stream Inlets and Outlets, 4/21/00

Parameter	Site 1		Site 2		Site 3		Site 4	
	Conc. (mg/L)	Mass* (g/s)	Conc. (mg/L)	Mass (g/s)	Conc. (mg/L)	Mass (g/s)	Conc. (mg/L)	Mass (g/s)
Total N (Kjeldahl)	0.64	1560	0.98	389	1.5	1700	0.64	4.2
Ammonia-N	<0.05	-	0.11	43.6	0.06	68	0.06	0.4
Nitrate + Nitrite-N	<0.1	-	0.14	55.5	2.3	2607	0.74	4.8
Soluble React. Phos.	<0.1	-	0.14	55.5	<0.1	-	<0.1	-
Total Phosphorus	<0.05	-	0.27	107	0.11	125	0.25	1.6
Total Susp. Solids	3	7312	6	2308	13	14,737	1	6.5

* Mass loadings are based on discharge measurements of 86 cubic feet per second (cfs) at Site 1, 14 cfs at Site 2, 40 cfs at Site 3, 0.23 cfs at Site 4.

Typically, nutrient concentrations and total suspended solids are higher in streams following the runoff event because the increased water flow results in increased erosion of soil and nutrients from the land. The nutrient concentrations reported for the storm samples did not reflect this theory. One possible reason for this may be that base flow conditions actually represented stagnant water which may result in higher concentrations of some pollutants. In addition despite the fact that two to five inches (5 to 9 cm) of rain fell during the storm event, runoff may not have been typical for that amount of rain. The area was still recovering from the near draught conditions experienced during the latter half of 1999. It is unlikely that the soil was saturated prior to the rainfall. Thus, a larger portion of the rainfall may have been absorbed by the soil than would be typical if the soil was already saturated.

The collection of discharge during the storm event allows for relative comparison between the inlet streams. The Tippecanoe River (Site 3) delivers the greatest amount of pollutants to the lakes for every parameter measured. This result is not surprising given the fact that the

Tippecanoe River has the largest drainage area of the three inlets, providing the greatest potential for runoff. Gaff Ditch (Site 2) recorded the highest concentration of phosphorus of all the inlet samples which is consistent with the measurements recorded for the base flow sampling. This high concentration results in the delivery of a similar mass of phosphorus to the lake by Gaff Ditch compared to the Tippecanoe River, despite the fact that the Tippecanoe River's discharge is nearly three times as great.

Discussion

The interpretation of a comprehensive set of water quality data can be quite complicated. Often, attention is directed at the important plant nutrients (phosphorus and nitrogen) and to water transparency (Secchi disk) since dense algal blooms and poor transparency greatly affect the health and use of lakes.

To answer these questions, limnologists must compare data from the lake in question to standards, if they exist, to other lakes, or to criteria that most limnologists agree upon. Because there are no nutrient standards for Indiana lakes, the Lake Webster results were compared with data from other lakes and with generally accepted criteria.

Comparison With Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in the Table 17 following. Vollenweider relates the concentrations of selected water quality parameters to a lake's *trophic state.* The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: *oligotrophic, mesotrophic, eutrophic,* and *hypereutrophic*. Lake conditions characteristic of these trophic states are:

Oligotrophic - lack of plant nutrients keep productivity low, lake contains oxygen at all depths, clear water, deeper lakes can support trout.

Mesotrophic - moderate plant productivity, hypolimnion may lack oxygen in summer, moderately clear water, warm water fisheries only - bass and perch may dominate.

Eutrophic - contains excess nutrients, blue-green algae dominate during summer, algae scums are probable at times, hypolimnion lacks oxygen in summer, poor transparency, rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer, few macrophytes, no oxygen in hypolimnion, fish kills possible in summer and under winter ice.

The units in the table are either milligrams per liter (mg/L) or micrograms per liter (µg/L). One mg/L is equivalent to one part per million (PPM) while one microgram per liter is equivalent to one part per billion (PPB). These are only guidelines; similar concentrations in a particular lake may not cause problems if something else is limiting the growth of algae or rooted plants.

Table 17. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

PARAMETER	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L or PPM)	0.008	0.027	0.084 *	>0.750
Total Nitrogen (mg/L or PPM)	0.661	0.753	1.875 *	-
Chlorophyll *a* (µg/L or PPB)	1.7	4.7 *	14.3	-

Values for Lake Webster are indicated by the asterisk (*) in the table above. The total phosphorus and total nitrogen concentrations exceed the mean concentration for eutrophic lakes while the chlorophyll *a* concentration exceeds the mean concentration for mesotrophic lakes.

Comparison With Other Indiana Lakes
The Webster Lake results can also be compared to other Indiana lakes. Table 35 presents data from 355 Indiana lakes collected during July and August 1994-98 under the Indiana Clean Lakes Program. The set of data summarized in the table represent mean values of epilimnetic and hypolimnetic samples for each of the 355 lakes. Again, it should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, could influence the water quality of lakes. Thus, it is difficult to predict or even explain the reasons for the water quality of a given lake.

Table 18. Water Quality Characteristics of 355 Indiana Lakes Sampled From 1994 thru 1998 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (m)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	Total Phos (mg/L)	SRP (mg/L)	Chl. *a* (mg/L)
Median	1.8	0.025	0.472	1.161	0.097	0.033	5.33
Maximum	9.2	9.303	11.248	13.794	4.894	0.782	230.9
Minimum	0.1	0.022	0.018	0.230	0.001	0.001	0
Lake Webster	**1.2**	**0.022**	**1.00**	**1.950**	**0.157**	**0.123**	**8.67**

The Lake Webster results for ammonia, total Kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus and chlorophyll *a* all exceed the median values for the Indiana lakes included in the table.

Using a Trophic State Index

In addition to simple comparisons to other lakes, lake water quality data can be evaluated through the use of a trophic state index or TSI. Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numerical index. Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI

The Indiana TSI (IDEM, 1986) ranges from 0 to 75 total points. The TSI totals are grouped into the following three lake quality classifications:

TSI Total	Water Quality Classification
0-25	highest quality (oligotrophic)
26-50	intermediate quality (mesotrophic)
51-75	lowest quality (eutrophic)

A rising TSI score for a particular lake from one year to the next indicates that water quality is worsening while a lower TSI score indicates improved conditions. However, natural factors such as climate variation can cause changes in TSI score that do not necessarily indicate a long-term change in lake condition. Parameters and values used to calculate the Indiana TSI are given in Table 19.

Table 19. The Indiana Trophic State Index

Parameter and Range	Eutrophy Points	Lake Webster
I. Total Phosphorus (ppm)		
A. At least 0.03	1	
B. 0.04 to 0.05	2	
C. 0.06 to 0.19	3	3
D. 0.2 to 0.99	4	
E. 1.0 or more	5	
II. Soluble Phosphorus (ppm)		
A. At least 0.03	1	
B. 0.04 to 0.05	2	
C. 0.06 to 0.19	3	
D. 0.2 to 0.99	4	4
E. 1.0 or more	5	
III. Organic Nitrogen (ppm)		
A. At least 0.5	1	

B.	0.6 to 0.8	2	
C.	0.9 to 1.9	3	3
D.	2.0 or more	4	
IV. Nitrate (ppm)			
A.	At least 0.3	1	
B.	0.4 to 0.8	2	
C.	0.9 to 1.9	3	0
D.	2.0 or more	4	
V. Ammonia (ppm)			
A.	At least 0.3	1	
B.	0.4 to 0.5	2	
C.	0.6 to 0.9	3	
D.	1.0 or more	4	4
VI. Dissolved Oxygen: Percent Saturation at 5 feet from surface			
A.	114% or less	0	
B.	115% 50 119%	1	
C.	120% to 129%	2	0
D.	130% to 149%	3	
E.	150% or more	4	
VII. Dissolved Oxygen: Percent of measured water column with at least 0.1 ppm dissolved oxygen			
A.	28% or less	4	
B.	29% to 49%	3	
C.	50% to 65%	2	3
D.	66% to 75%	1	
E.	76% 100%	0	
VIII. Light Penetration (Secchi Disk)			
A.	Five feet or under	6	6
XI. Light Transmission (Photocell) : Percent of light transmission at a depth of 3 feet			
A.	0 to 30%	4	
B.	31% to 50%	3	
C.	51% to 70%	2	4
D.	71% and up	0	

X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

A.	less than 3,000 organisms/L	0	
B.	3,000 - 6,000 organisms/L	1	
C.	6,001 - 16,000 organisms/L	2	
D.	16,001 - 26,000 organisms/L	3	
E.	26,001 - 36,000 organisms/L	4	
F.	36,001 - 60,000 organisms/L	5	1
G.	60,001 - 95,000 organisms/L	10	
H.	95,001 - 150,000 organisms/L	15	
I.	150,001 - 5000,000 organisms/L	20	
J.	greater than 500,000 organisms/L	25	
K.	Blue-Green Dominance: additional points	10	
		TOTAL	28

The Indiana Trophic State Index value calculated for Lake Webster during this study was 28 (see Table 19). This value falls within the “intermediate quality” range of the index. This conclusion is inconsistent with the physical appearance of the lake (abundant rooted aquatic plants and poor transparency) and with the measured values for phosphorus. There are several possible reasons for this.

1) In lakes with high non-algal turbidity (suspended inorganic material), light penetration (and therefore photosynthesis) is reduced. This would yield fewer algae in the samples. Algae can account for a total of 35 trophic points in the Indiana TSI.
2) The Indiana TSI does not account for rooted aquatic plants.
3) The dense growths of rooted aquatic plants ringing the lake in the shallow waters intercept runoff water, trapping suspended solids. These rooted plants also compete with the algae for available phosphorus.

The Indiana TSI has not been statistically validated. It tends to rely heavily on algae and does not weigh poor transparency or nutrients high enough in the total score. The Indiana TSI’s reliance on algae may be of particular concern this year. Algae densities for all lakes in Indiana were depressed this year (Bill Jones, Director of the Indiana Clean Lakes Program, personal communication). The drought may be responsible for decrease in regular inputs of inorganic nutrients from runoff. In addition, lower inlet flows may have reduced turbulent mixing, including settling of plankton. For these reasons, the algal densities may be low in 1999. This will in turn skew results of the Indiana TSI.

The Carlson TSI

The Carlson TSI may be more appropriate to use in evaluating Indiana lake data. Developed by Bob Carlson (1977), the Carlson TSI is the most widely used and accepted TSI. Carlson analyzed summertime total phosphorus, chlorophyll *a*, and Secchi disk transparency data for numerous lakes and found statistically significant relationships among the three parameters. He developed mathematical equations for these relationships and these equations form the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll *a* or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass (Figure 19).

As a further aid in interpreting TSI results, Carlson's scale is divided into four lake productivity categories: oligotrophic (least productive), mesotrophic (moderately productive); eutrophic (very productive) and hypereutrophic (extremely productive).

Using Carlson's index (Figure 19), a lake with a summertime Secchi disk depth of 1 meter would have a TSI of 60 points (located in line with the 1 meter). This lake would be in the eutrophic category. Because the index was constructed using relationships among transparency, chlorophyll, and total phosphorus, a lake having a Secchi disk depth of 1 meter would also be expected to have 20 μg/L chlorophyll and 43 μg/L total phosphorus.

Not all lakes have the same relationship between transparency, chlorophyll and total phosphorus as Carlson's lakes do. Other factors such as high suspended sediments or heavy predation of algae by zooplankton may keep chlorophyll concentrations lower than might be otherwise expected from the total phosphorus or chlorophyll concentrations. High suspended sediments would also make transparency worse than otherwise predicted by Carlson's index.

It is also useful to compare the actual trophic state points for a particular lake from one year to the next to detect any trends in changing water quality. While climate and other natural events will cause some variation in water quality over time (possibly 5-10 trophic points), larger point changes may indicate important changes in lake quality.

CARLSON'S TROPHIC STATE INDEX

```
                Oligotrophic     Mesotrophic    Eutrophic   Hypereutrophic

               20    25    30    35     40    45    50     55    60    65     70    75    80
Trophic State
   Index       +-----------------------------------------------------------------------+

                 15    10  8 7  6   5    4     3    2   1.5     1          0.5     0.3
Transparency
  (Meters)     +----------------------------------*-----------------------

                  0.5      1      2      3  4  5  7    10  15  20  30  40  60 80 100 150
Chlorophyll-a
(µg/L or PPB) +-------------------------------*-------------------------+

Total           3      5      7     10      15   20  25 30   40  50  60  80  100    150
Phosphorus
(µg/L or PPB)  +----------------------------------------------------------*--+
```

Figure 19. Carlson's Trophic State Index with Lake Webster values indicated by (*).

Analysis of Lake Webster transparency and chlorophyll *a* data according to Carlson's TSI shows that these parameters register in the eutrophic categories (see asterisks in figure above). The phosphorus data fall within the hypereutrophic range. This is similar to the results comparing the lake Webster data with Vollenweider's data and is a better measure of the true trophic status of Lake Webster.

Other Parameters

Plankton

The plankton population, which includes algae, at the time of sampling was very sparse. Diatoms and yellow-brown algae were dominant. Blue-green algae, the algal group most often associated with nuisance blooms, accounted for only 6% of the total number of cells in the sample.

Algae depend on light and several important nutrients for their growth. If any of the essentials needed for growth are in limited supply, algal growth will not achieve its maximum rate. The material in least supply is known as growth limiting. The ratio of nitrogen and phosphorus in plant tissue is 7 parts nitrogen to 1 part phosphorus. In Lake Webster, the ratio of total nitrogen to total phosphorus in the surface water where growth can occur is 12.4 : 1. Because there is much more nitrogen available relative to phosphorus, phosphorus is the limiting nutrient in Lake Webster. This means that if more phosphorus is added to the water, more algal growth will result. Therefore, to prevent additional algal growth or to reduce existing algal populations, phosphorus additions to the lake must be controlled.

Plankton, including algae, are an important part of the lake ecosystem. They form the base of the aquatic food chain. Many fish species, including bluegill, depend on these organisms as a food source. Thus, low plankton densities could have an impact on a lake's ability to support fish. However, the low plankton densities observed in Lake Webster are not of immediate concern. This low plankton density is consistent with results observed in other Indiana lakes in 1999. The drought-like conditions of 1999 are likely responsible for this apparent decrease in plankton density from the 1998 density (See Table 9). Lake Webster appears to have a sufficient amount of nutrients to support a more robust plankton community. Higher plankton densities will likely be observed again once weather conditions return to normal.

Water Budget

Inputs of water to the Lake Webster are limited to:

- direct precipitation to the lake
- discharge from the inlet streams
- sheet runoff from land immediately adjacent to the lake
- groundwater

Water leaves the lake from:

- discharge from the outlet channel to James Lake
- evaporation
- groundwater

There are no gauges on the lake to measure water inputs or outputs so we must estimate this from other records. Direct precipitation to the lake can be calculated from mean annual precipitation and the lake's surface area. Runoff from the lake's watershed can be estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gauged watershed to the total amount of precipitation falling on that watershed. The nearest gauged watershed to Lake Webster is a U.S.G.S. gauging station on the Tippecanoe River southeast of North Webster, Indiana (Stewart et al., 1999). The 11-year (1987– 1998) mean annual runoff for this watershed is 13.54 inches. With annual precipitation of 35.52 inches (Staley, 1989), this means that 38.1% of the rainfall falling on this watershed runs off on the land surface. No groundwater records exist for the lake so groundwater inputs were assumed to equal outputs. Annual water budget input estimates for Lake Webster are summarized in Table 20.

Comparing this input water volume (35,390 acre-ft/yr) to the combined volume of the Webster and the Backwaters (6,056 acre-ft) results in a *hydraulic residence time* of 0.17 years. This means that it takes approximately 63 days for the lake's entire volume to be replaced by direct precipitation and surface runoff. This value is so short due to the very large size of Lake Webster's watershed. The hydraulic residence of many natural *drainage lakes* (those with surface inlets and outlets) in Indiana is about one-half to one year.

Table 20. Annual Water Budget Estimates for Lake Webster and the Backwaters.

Category	Operation	Result
Direct Precipitation	Mean annual precip x lake surface area	(35.52 in/yr)(1 ft/12 in)(769 acres) = **2,276 acre-feet/yr**
Surface Runoff	Mean annual runoff x watershed area	(13.54 in/yr)(1ft/12 in)(29,348 ac) = **33,114 acre-feet ft^3/yr**
TOTAL		**35,390 acre-feet/yr**

Phosphorus Budget

Since phosphorus is the primary nutrient regulating the growth of algae in lakes, it is helpful to develop a phosphorus budget for lakes. The limited scope of this LARE study did not allow for the outright determination phosphorus inputs and outputs. Therefore, a standard phosphorus model was used to estimate the phosphorus budget. Reckhow et al. (1980) compiled phosphorus loss rates from various land use activities as determined by a number of different studies, and calculated phosphorus export coefficients for each land use in the watershed. For this model conservative estimates of these phosphorus export coefficient values, which are expressed as kilograms of phosphorus lost per hectare of land per year, were used. These values were multiplied by the amounts of land in each of the land use categories to derive an estimate of annual phosphorus export (as kg/year) for each land use per watershed (Table 21).

Direct phosphorus input via precipitation was estimated by multiplying mean annual precipitation in Kosciusko County (1.13 ft/yr) times the surface area of Lake Webster and the Backwaters (769 acres) times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L). Finally, the phosphorus load due to septic systems was estimated by multiplying the approximate number of homes with septic systems on the lake (106 permanent; 192 seasonal) times an estimated 3 people per home, times an occupancy rate of either 365 or 90 days per year per home, times a phosphorus export coefficient of 0.6 kg per capita-year, times a soil retention coefficient of 0.85 (Reckhow and Simpson, 1980). Under ideal circumstances, all of the phosphorus in septic systems is trapped in the soil resulting in none reaching the lake. For purposes of this model, it was assumed that 15% of the phosphorus entering septic systems reaches the lake and 85% is trapped in the soil. The results, shown in Table 22, yielded an estimated 5823 kg of phosphorus exported from the watershed to the lake per year. This is likely an overestimate since some amount of the phosphorus lost from watershed land uses will be trapped in the lakes upstream from Webster.

Table 21. Estimated Watershed Phosphorus Export to Lake Webster.

LAND USE	P-export (kg/ha-yr)	Land Area (ha)	P-export (kg/yr)
Row Crop	0.6	8176.5	4905.9
Pasture	0.3	356.3	106.9
Forest	0.2	2722.6	544.5
Shrubland	0.2	546.2	109.2
Residential	0.5	75.5	37.8
TOTAL			5704.3

Table 22. Estimated Phosphorus Loading by Source.

SOURCE	PHOSPHORUS LOAD
Phosphorus from Land Use Activities	5704.3 kg/yr
Precipitation Phosphorus	84.2 kg/yr
Septic Systems	34.7 kg/yr
TOTAL PHOSPHORUS LOAD	5823.2 kg/yr

Phosphorus Loading

A phosphorus-loading model such as the widely used Vollenweider (1975) model allows for the examination of the relationships among the primary parameters that affect a lake's phosphorus concentration. Vollenweider's empirical model says that the concentration of phosphorus ([P]) in a lake is proportional to the areal phosphorus loading (L, in g/m^2 lake area - year), and inversely proportional to the product of mean depth ($\bar{z}$) and hydraulic flushing rate (?) plus a constant (10). Areal phosphorus loading (L) is calculated by dividing the total annual phosphorus mass loading (in grams per year) by the surface area of the lake (in m^2)

$$[P] = \frac{L}{10 + \bar{z}r}$$

During the August 12, 1999 sampling of Lake Webster, the mean epilimnetic phosphorus concentration was 0.045 mg/L and the mean hypolimnetic phosphorus concentration was 0.269 mg/L. Considering the respective volumes of the epilimnion and hypolimnion from the depth-volume curve (Figure 5), a <u>volume-weighted</u> mean phosphorus concentration for the lake of 0.092 mg/L was derived. For this, the middle metalimnion (6 meter depth) was used as the division between the epilimnion and hypolimnion.

Now it is useful to ask the question, "How much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.092 mg/L in Lake Webster?" By using this mean concentration, mean depth, and flushing rate in Vollenweider's phosphorus loading model and solving for L, an areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 2.205 g/m^2-yr was calculated. This means that in order to get a mean phosphorus concentration of 0.092 mg/L in the lake, a total of 2.205 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total areal phosphorus loading (L_T) is composed of external areal phosphorus loading (L_E) and internal phosphorus loading (L_I). Since L_T = 2.205 g/m^2-yr and L_E = 1.871 g/m^2-yr (calculated from the watershed loading in Table 16), then internal phosphorus loading (L_I) equals 0.334 g/m^2-yr. Thus, internal loading accounts for approximately 15% of total phosphorus loading to Lake Webster. This should be considered as a low estimate of internal phosphorus loading for the lake since external phosphorus loading was likely overestimated.

This internal loading is from dead plants, fertilizers, and other organic material that are stored in the sediments. This phosphorus can dissolve and re-enter the water above the sediments lacks oxygen. The resulting internal phosphorus loading can be a significant source of phosphorus in lakes and may promote additional plant growth (Figure 20).

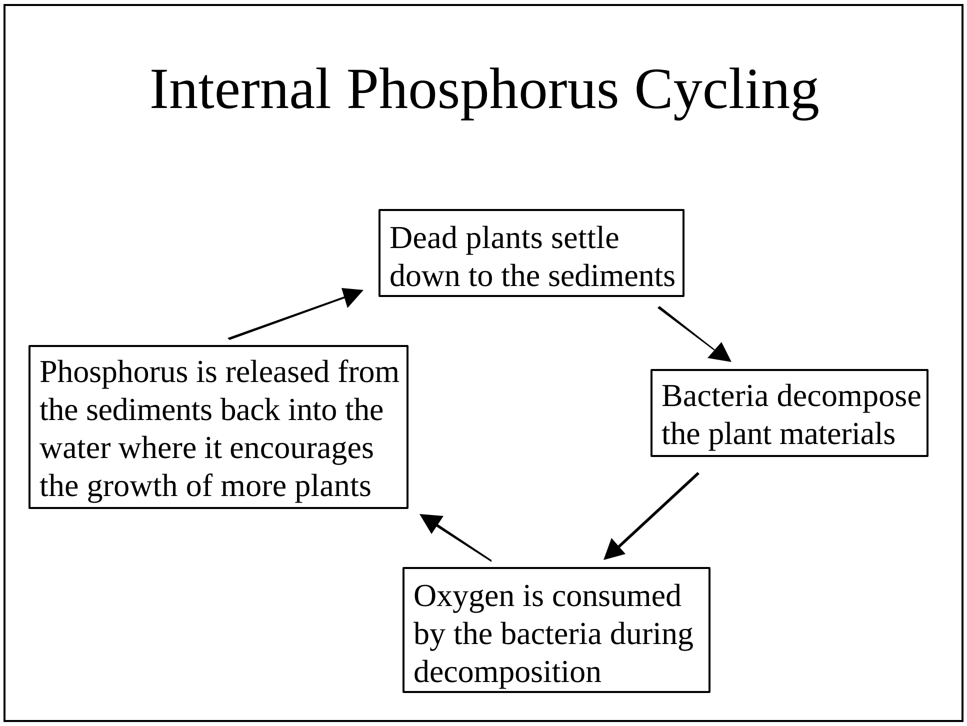


Figure 20. Anoxia at the sediments can cause chemically reducing conditions that can cause internal phosphorus release.

The significance of this areal loading rate is better illustrated in Figure 21 in which areal phosphorus loading is plotted against the product of mean depth and flushing rate. Overlain on this graph is a curve, based on Vollenweider's model, which represent an acceptable loading rate that yields a phosphorus concentration in lake water of 30 µg/L (0.03 µg/L). Lake Webster's loading rate falls within the excessive loading portion of the graph.

This figure can also be used to evaluate management needs. For example, total areal phosphorus loading from all sources (2.205 g/m^2-yr) would need to be reduced to 0.71 g/m^2-yr to result in a mean lake water concentration of 30 µg/L. This represents a reduction in phosphorus mass loading to the lake of nearly 4653 kg, a 32% reduction in total annual phosphorus loading. While this lofty goal likely cannot be achieved, the goal of reducing phosphorus loading from all sources is a valid one.

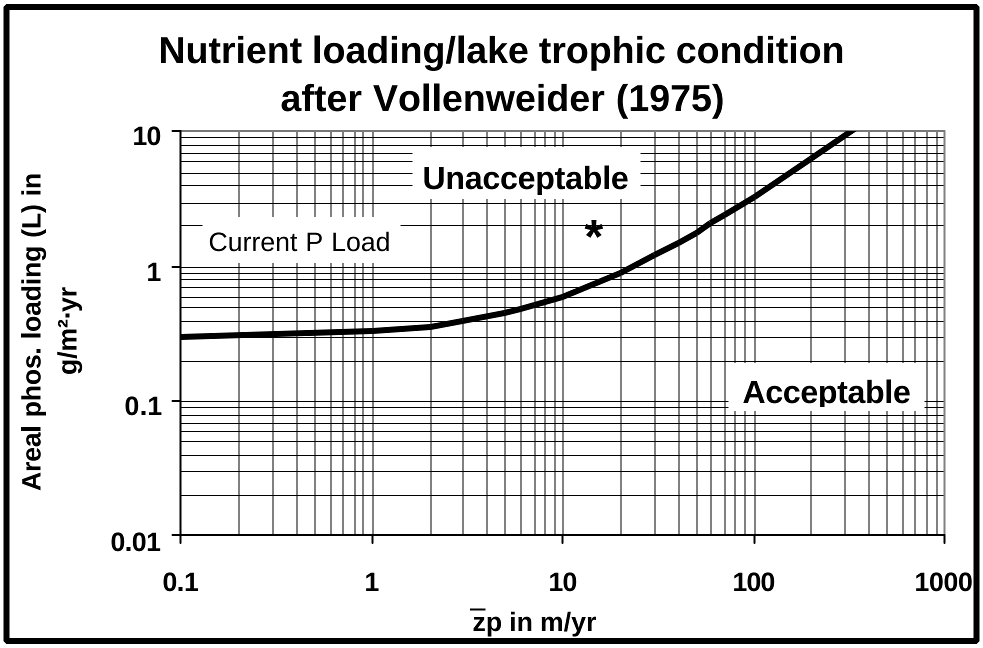


Figure 21. Current phosphorus loading rate for Lake Webster compared to a target loading rate that would result in an acceptable phosphorus concentration of 0.03 mg/L.

CONCLUSION

Lake Webster is a relatively typical eutrophic Indiana lake characterized by high phosphorus concentrations, poor transparency, excessive rooted plant growth, and anoxia in deep water. Symptoms of eutrophication appear to be worsening with time.

There is likely a significant amount of undecomposed organic material on the bottom sediments. This material exerts a biochemical oxygen demand (BOD) in the deeper waters. As decomposer organisms (bacteria and microbes) feed on this organic material, they consume the available oxygen. Because of this, dissolved oxygen is virtually absent from the bottom half of the lake (water >6 meters deep). This reduces available habitat for fish and other aquatic organisms. A further consequence of low oxygen levels is the creation of chemically reducing conditions. With reducing conditions inorganic phosphorus, otherwise tied up with iron and other cations in the sediments, is released back into the water. There is evidence of this internal phosphorus release in the higher hypolimnetic soluble phosphorus concentration (0.269 mg/L) compared with the epilimnetic concentration (0.045 mg/L). Finally, the major product of bacterial decomposition is ammonia, and ammonia concentrations are thus elevated in the hypolimnion of the lake.

Fortunately, most of this internal loading of phosphorus occurs in the summer when the lake is stratified and the released phosphorus is confined to the hypolimnion where it does not contribute to additional algal growth. This phosphorus mixes with the surface waters during fall overturn. By then (late September) algal growth is limited by shorter day length and cooler temperatures. Over time, phosphorus concentrations will continue to increase throughout the lake and the growth of additional algae and rooted plants will occur if the phosphorus loadings to the lake are not reduced.

Lake Webster's large watershed is an important factor in the lake's problem with eutrophication. A smaller watershed with the same proportion of land use practices would deliver proportionally fewer nutrients and sediments to the lake. Because of this, successful lake management will require extra vigilance in promoting watershed best management practices (BMPs) to keep the nutrients and soil on the land and out of the waterways. As it is now, several of the inlet streams carry significant concentrations of phosphorus, nitrogen, and suspended solids during low flow into the lakes. These concentrations could be significantly higher during storm runoff events.

RECOMMENDATIONS

Like all efforts to manage lakes, limited financial and time resources will constrain any effort to manage Lake Webster and the Backwaters. Management recommendations should be prioritized in order to achieve the greatest improvement in lake's health with the limited resources. Unfortunately, prioritizing recommendations is difficult when multiple pollutant sources contribute to the lake's impairment, as is the case for Lake Webster. The following is a discussion of where financial and time resources should be spent to provide the greatest benefit to the lakes as a whole. Specific benefits to the lake from each proposed treatment that are detailed in the preceding sections are not repeated here. Please refer to the text for a discussion on the recommended treatments' benefits.

The phosphorus modeling suggests that most of the phosphorus load (the limiting nutrient) originates from the watershed. Watershed sources are also largely responsible for the sediment load to the lake, since little shoreline erosion was observed on the lakes. Thus, watershed treatments are given a higher priority than in-lake treatments. Watershed treatment includes implementation of buffer strips, restriction of livestock from waterways, and restoration of small wetlands. Recommended projects concentrate on Gaff Ditch and the Tippecanoe River since inlet sampling identified these inlets as the most significant contributors of pollutants.

Management should also focus on urban sources of sediment inputs particularly in the northern and western portions of the lake. Sediment accumulation in these areas affects lake residents' ability to use the lake for one of its designated purposes, recreation. Recommended treatments include construction of a stormwater filter or wetland, installation and maintenance of storm drain filters, and selected dredging of specific sites on the lake. Dredging is recommended only in areas where excessive sediment inputs have restricted access to the lake and may be contributing to internal phosphorus loading. Dredging is not recommended as a means to deepen the lake beyond its original depth. A complete feasibility study would be needed to ensure dredging occurred only in appropriate places.

Homeowner BMPs and some in-lake management are also recommended. Homeowner BMPs should not be ignored. Individually, implementation of shoreline BMPs may not generate noticeable results in the lake. Cumulatively, however, they can greatly enhance the lake's health. While financial resources may limit the implementation of recommendations, such as completing the installation of a sanitary sewer and developing an aquatic plant management plan, serious consideration should be given to these recommendations.

It is important to note that many of these recommendations may be implemented simultaneously. A concerted effort by lake residents and watershed property owners will, over time, reverse the eutrophication observed in Lake Webster and the Backwaters.

Based on this discussion, the following is a prioritized list of recommendations:

1) Designate a person or committee to work with the Soil and Water Conservation District to implement best management practices in the entire watershed. Specific treatment includes buffer or filter strips along Gaff Ditch from 750 West Road (Whitley County) east to its beginning and the Tippecanoe River between Smalley Lake and Big Lake. Also have the SWCD investigate the potential of restoring two small wetland filters at the Gaff Ditch headwaters at County Roads 750 North and 650 West, Whitley County.

2) Construct a stormwater filter or wetland on the property to the northeast of the intersection of State Road 13 and Epworth Forest Road.

3) Work with the landowner at County Roads 1050 West and 275 East to fence cattle away from the Tippecanoe River and construct a livestock watering pond.

4) Retrofit 11 city regulated storm drains with pollutant removal devices and develop an inspection and maintenance plan for these devices.

5) Designate a person or committee to contact the Whitley County Highway Department about stabilizing the bridge abutments on Gaff Ditch at County Road 750 West, which are severely eroding.

6) Residential Owner Recommendations:
   a) Residents around the lake should use only phosphorus-free fertilizers.

b) Residents around the lake should consider natural stone or aquatic vegetation to protect their shoreline from erosion instead of concrete and sheet pile seawalls.
c) Residents should examine all drains that lead from roads, driveways, or rooftops to the lake and consider alternate routes for these drains that would filter pollutants before they reach the lake.
d) Residents should not place any organic debris such as lawn clippings, leaves, or animal waste into or adjacent to the waters edge.
e) Lake users should use idle speeds in shallow water areas to limit prop wash and consider marking these areas with buoys.
f) Residents on the east end of the lake should clean septic systems regularly.

7) Dredge select areas of sediment build-up including the NW corner of Lake Webster, the east side of Eagle Point, Echo Bay (former effluent discharge site of Epworth Forest), the bay on the east side of Yellow Banks and limited areas along the west bank of the Backwaters.

8) As funding and other resources allow, consider the feasibility of stocking spring yearling muskellunge rather than fall stocking. Continue stocking muskellunge near dense aquatic macrophyte or other cover in an effort to decrease initial stocking mortality.

9) Develop an aquatic plant management plan for the lakes, which includes a focus on Eurasian water milfoil and duckweed, two problem species on Webster and the Backwaters. Any management techniques recommended by such a plan should recognize that considerable financial resources have already been invested in the current management strategy (Sonar treatment). Consider the release of the native weevil (*Euhrychiopsis lecontei*) in the Backwaters to reduce Eurasian water milfoil density.

10) Complete the sewering of the entire lake as funding allows.

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